MONOGRAPHS ON TEA PRODUCTION IN CEYLON.

No. 1

THE WORK OF THE AGRICULTURAL CHEMISTRY DEPARTMENT OF THE INSTITUTE.

MONOGRAPHS ON TEA PRODUCTION IN CEYLON

PREFACE.

IT is proposed to publish a series of special Monographs covering various aspects of tea production in Ceylon. These will, so far as possible, give a general picture of the position at the present time as revealed by the work of the Institute.

It is hoped that these Monographs will prove of convenience to the planting community in general and others interested in tea production, in-so-much-as the information thus presented will reduce to some extent the necessity to refer to back numbers of the Institute's publications, many of which are now out of print and unavailable on certain estates. Back reference will, of course, still be required for a more detailed account of specific problems, and this will be facilitated by the bibliography given at the end of each Monograph.

ROLAND V. NORRIS.
Director,
Tea Research Institute of Ceylon.

February, 1949.

THE

WORK OF THE AGRICULTURAL CHEMISTRY DEPARTMENT

1927-1948

BY

T. EDEN, D.Sc., A.R.I.C.

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THE WORK OF THE AGRICULTURAL CHEMISTRY DEPARTMENT 1927-1948.

T. EDEN, D.Sc., A.R.I.C.

INTRODUCTION.

The following chapters have been written to summarise the work of the past 21 years. There are two methods of doing so, first a discussion of general principles that have emerged from detailed work and, second the description of the evidence on which such principles have been based together with indications of their practical bearing on tea cultivation. I have already set forth my views on general principles in "Elements of Tropical Soil Science," so the pages that follow will conform to the second method. This account is by no means a full description of the activities of the department. Promising lines of enquiry sometimes fail to mature, and have to be re-orientated. Besides, a bulletin of this nature is unsuitable for detailed accounts of the very varied activities of even one department. I have therefore restricted the text to a consideration of the main lines of work which have given definite results.

It goes without saying that the work here described is not that of a single person but of a team. Without the continuous help and co-operation of the other members of my department, none of the investigations that have sustained my interest and curiosity for so many years could have been started, let alone completed.

Mr. E. N. Perera, chemical assistant, and Mr. M. Piyasena, senior field assistant, have been actively connected with the work of the department from its inception and their association with the large amount of experimental data that has been collected calls for special recognition and gratitude. Other workers who have also contributed considerably are Mr. F. P. Jayawardene, field assistant ; and Mr. C. A. de Silva, B.Sc., and Dr. J. G. Shrikhande, who for about half the time under review were Research Assistants in the Department.

I have also freely drawn on the services of Mr. G. D. Austin and Mr. W. T. Fonseka of the Entomological Department for help at the Passara Sub-Station. Mr. Austin has also very kindly prepared the bibliography in Appendix 2.

Nor is the contribution of field attendants negligible where a crop comprises so many harvests. During this period I have been ably served by S. D. Fernando, A. Joseph and D. H. de Saram.

To all my departmental staff and my colleagues, who have so often filled the Socratic role in discussing the results here presented, I offer my very grateful thanks

CHAPTER 1.

THE USE AND INTERPRETATION OF FIELD EXPERIMENTS.

Although it was Sir Humphrey Davy who coined the term Agricultural Chemistry and Baron von Liebig who brought the subject into a prominence that shook scientific circles in both the old and the new world, the real foundations of the chemistry of the farm were laid not by chemists but by well-educated farmers in the persons of J. B. Boussingault, in Alsace, and Sir J. B. Lawes at Rothamsted. Both approached their subject by way of field experiments, and though it is now becoming the fashion to separate the soil chemist from the agronomist, to the disadvantage of both, the crop-cum-soil approach proved immensely stimulative and successful.

The work of this department has been based on a similar approach. The choice was deliberately made for two reasons. First, the problems that face a commodity research station such as the Tea Research Institute are, on the cultural side, practical problems of soil and crop management. Physiology, pathology, biochemistry, pedology ; all must eventually play their part in elucidating these problems, but their definition and broad solution lies in the field. Second, at the time that the Institute was founded, the revolutionary statistical researches of Professor R. A. Fisher had thrown a new light on the possibilities of field experiments, properly controlled and adequately interpreted, as a powerful investigational weapon. It had been my good fortune to be in change of the Rothamsted Experiments at the time when Fisher's methods reached fruition and my privilege to put his methods into operation on a field scale for the first time.

Up to that time field experimental trials on tea in Ceylon had been confined to Joseph Fraser's single 'demonstration plot' methods at Pitakande, and to a few sparsely replicated trials over a short period at the Government Experiment Station at Peradenyia. In Assam replication was not usually practised. In the Dutch East Indies, though replication was employed, it was not used for estimating the experimental error, and the yields of the separate replications were frequently not separately recorded. In these circumstances the first consideration for the department of Agricultural Chemistry was to explore field experimental methods suitable for

tea, and to ascertain their accuracy, in readiness for the establishment of definite experiments on soil and crop management so soon as the Tea Research Institute could acquire a suitable estate as its home.

The problem appeared to be a formidable one for a variety of reasons. To anyone reasonably well versed in the vagaries of soil heterogeneity, the average estate seemed to offer the worst possible terrain on which accurate comparisons could be made. The necessity of harvesting some 40 to 50 times a year with all the possibilities of error in weighing and recording; the variety of weather conditions that would affect the weighed yields; the individuality of the plucker which introduced a large human element: all these factors militated against the prospect of achieving even reasonable accuracy in the task at hand. It is beyond doubt that apart from Fisher's researches the task would have been impossible.

Between two and three years were needed to work out the elements of a technique which would safely bear the superstructure of detailed experimentation later to be imposed upon it. The work was carried out on a field generously loaned by the Ceylon Tea Plantations Co., Ltd. on the Scrubs Estate, Nuwara Eliya. One hundred and forty-four plots were laid out on this field and their yield behaviour, singly and in groups, was observed over a period of twenty months. The results of this uniformity trial have set the norm for all the experiments since undertaken. The worthwhileness of three years purely technical and theoretical approach to a major line of work is borne out by the fact that, so long as the indications of this investigation have been given due consideration, no experiment of inadequate accuracy has emerged, and no experiment of unascertainable precision has been carried out.

This technical trial established a number of important points. Field experimental plots are after all only samples of a field or an estate. If deductions from their behaviour are to be drawn with any pretence of validity in the wider sphere of estate practice, they must be representative. There is a persistant fallacy that to be representative a plot must be large; very nearly the opposite is true. Representativeness lies more often in numbers and in distribution than in size. The Scrubs investigation showed that a convenient and reliable size for a plot could in favourable circumstances be as low as a hundred bushes and need not, except in exceptional circumstances, exceed 250-300. It was better to use the available land for securing high replication than for unduly increasing plot size. Exceptions were made when the necessity to provide enough leaf for experimental manufacture arose. Fertility gradi-

ents across the contours proved to be of quite appreciable importance. Consequently, when reasonably level land has not been available, plots carrying treatment comparisons have purposely been distributed along the contours. The variation in plucking standard from plucker to plucker turned out to be less than had been feared, and interference with accuracy on this account has not been of much trouble, provided that supervision was adequate. The Scrubs uniformity trial suggested that the correlation between the behaviour of a plot on consecutive occasions was so high that it might be possible to do experiments in places more or less remote from the central research station, and to have the yields recorded by trained staff at intervals of every third plucking instead of continuously. This method was given a trial both at Passara and at Wikiliya but was not a success. Close supervision by those trained to recognise the exacting requirements of the work is necessary for experimental work. This naturally is not available apart from the personnel of the research station. Some of the more recent refinements of experimental technique have proved unsuitable for situations such as ours, but with replications between 12 and 24, using randomised blocks and the principles of confounding, low errors have been achieved. Standard errors of mean differences as low as 2.5 to 3.0 per cent. have been attained in these trials with the corollary that significant differences as low as 5 to 6 per cent could be relied on. The comparability of all records under variable weather conditions has been maintained by reducing all field weights to dry matter yields. This has been done on the basis of dry matter samples from each plot taken at the time of weighing in the field.

Without statistical examination of field experimental data the interpretation of experimental results becomes subjective. By using statistics, provided they are correctly employed, an objective criterion of accuracy and interpretation is made possible, which is not dependant on individual predilections which exist even though they are not consciously exercised.

CHAPTER 2.

THE RESPONSE OF THE TEA CROP TO FERTILIZER NUTRIENTS.

With a technique of experimentation of ascertainable accuracy at hand, the department started its exploration of fertilizer requirements in November 1930 at St. Coombs, immediately after the Institute's removal to its permanent headquarters. The form which this earliest experiment took was determined by the prevailing agricultural opinions of the time. Some of these were accepted and incorporated into the practical details of the experiment. Others were made the object of enquiry and comparison. It will be useful, since memories are so short, to set down the opinions of 1930 so as to make the following account intelligible. It will be convenient to deal with the major nutrients one by one.

Nitrogen.—This nutrient was generally thought to be essential in any manurial prescription, but its effect on quality in tea was debatable. The idea that there was an association between rush crops and poor tea was firmly established in people's minds, and any process which produced a forcing growth was therefore naturally suspect. On the whole, nitrogenous manuring was carried out using modest quantities varying from 25 to 40 lb. of nitrogen, and only in exceptional circumstances were higher levels consistently recommended. There were definite opinions not only on quantity of nitrogen but on the kind of compound to be used. Organic manures such as blood meal, groundnut cake or fish offals were believed to be characterised by much slower availability than inorganic manures of which sulphate of ammonia was the most widely used. The supply of manurial nutrients to the bush was envisaged as a process which proceeded by gradual stages and it was therefore almost an article of faith that a manure mixture should contain several kinds of nitrogenous compound so as to give the 'relay race' idea full scope. Occasionally records were sent to the Institute showing as many as seven different forms. Coupled with this idea of piecemeal absorption of nitrogen were cognate ones to the effect that the results from organic manures were more lasting; that inorganic nitrogen produced flush but was of little use to the bush as a whole. If inorganic manures were to be used they should be assigned, so it was said, to the period immedi-

ately after pruning when rapid growth was in any case desirable and when quality in tea was not a consideration of such importance.

Potash.—Ideas on the response and function of potash were conflicting. Whilst some believed that high potash favoured wood growth, others believed that Ceylon tea soils contained sufficient for normal requirements.

Phosphoric Acid.—The dominating idea was that phosphoric acid promoted root growth and should therefore be applied liberally in the early stages of recovery from pruning. Quantities in excess of 100 lb. per acre are on record in the files of the Institute. Early Indian work under Mann had suggested that phosphoric acid might be a favourable factor in promoting good quality.

Time of Application.—The annual crop statement and the annual financial statement were very influential features in determining times of application, although the pruning cycle is the logical unit on which to plan cultural operations. Consequently, immediately after pruning a manurial application was given in order to give the bush a fillip on the road to recovery, and thereafter annual applications of manure were usual. Within this more or less rigid framework there was a good deal of variety. Anything in the nature of a standard mixture to be used on every manurial occasion would have been considered very queer, and this view persisted until the war made standard mixtures inevitable. The variation in nutrient ratios and constituents of the mixtures was very marked and, as far as my investigations were able to ascertain, quite without rational support.

The process of confirming or confuting the prevailing ideas of the early thirties is by no means yet complete, but the various experiments that the Institute has carried out have given reliable information on some of the points at issue, and have raised other equally interesting and controversial problems.

The general pattern of response to nitrogenous nutrition recurs consistently over the period of the 18 years during which it has been a constant object of study. The first fact that emerges is that tea responds very rapidly to applied nitrogen. What quantities can be economically used depends on considerations some of which are not agricultural, but the experiments here show that, given normal conditions, the increase of crop produced by nitrogenous manure is proportional to the amount used, at any rate up to applications of 80 lb. per acre per annum. This must not be interpreted as meaning that anyone can apply 80 lb. of nitrogen to tea in any condition, at any time, and get a worthwhile response. In all agricultural practice there obviously comes

a stage at which heavier manuring produces no further benefit, and in some instances gives rise to an actual depression of crop; but properly used there are no signs that this state of affairs will manifest itself on good tea at 80 lb. per acre doses. By way of illustration Table I gives the figures for the cycle 1940-43 which began after nine years of consistent nitrogenous manuring.

TABLE I.

Yields in lb. per acre in 3-year Pruning Cycle showing that equal increments of N. give (within error limit) equal increments of crop.

Nitrogen applied in lb.	1st Year		2nd Year		3rd Year	
	Yield.	Increment.	Yield.	Increment.	Yield.	Increment.
N 40	509		962		611	
		46		119		126
N 60	555		1081		737	
		44		128		132
N 80	599		1209		869	

Such regularity in response, due in part to the fortunate fact that the yield of tea is derived from the vegetative organs of the plant, allows further deductions to be drawn. Since the proportionality between nutrient dose and yield increment is so close (and this applies in the lower range of doses N0 to N40 which are not here displayed) it is possible to answer in the affirmative the frequent question whether small doses are worth while. This linear response is truly remarkable when we come to consider the variability of the cultural and climatic conditions under which it is produced. If we imagine 40, 60 and 80 lb. of nitrogen supplied to three different areas of tea and consider the wasting forces at work tending to reduce the efficiency of these doses in the soil and to the plant, it seems remarkable, if we stipulate that this nitrogen is released little by little (the relay race), that adverse weather or seepage conditions should, over a long period of months, produce wastage from 80 lb. of applied nitrogen in exactly the same ratio as from 40 or 20 lb. So long as the nitrogen is in the soil it is subject to vagaries of effect which are unpredictable. When the nitrogen is in the plant then it is either stored or used for growth. To clinch the matter detailed physiological work would be needed, but the data suggest that the absorption of the nutrient

by the plant is fairly rapid over a limited period of time and that it is not affected by the grosser variability associated with long periods. The climatic condition which seems most markedly to reduce efficiency in nitrogenous response is drought. This aspect will be dealt with rather more specifically later.

Over a period of 12 years the nitrogen used in one of the Institute's experiments was applied in two forms, sulphate of ammonia and blood meal, and for 9 years there was also a groundnut cake comparison. The behaviour of these different manures, one 'inorganic' and two 'organic' was remarkably uniform. The average relative yield responses over the period were :—

Sulphate of ammonia	...	103
Blood meal	...	98
Groundnut cake	...	100

The exploration of this qualitative difference came to an end when it became impossible to import organic manures and the stocks we had built up to tide us over the war years gave out. This equivalence of yield response disposes effectively of the 'relay-race' theory of nitrogenous manuring and makes a nutritional curiosity of the prescription that contained nitrate of potash, sulphate of ammonia, blood meal, castor cake, groundnut cake, whale guano and bone meal.

The most significant results from these now, long-standing, experiments has been the rise in efficiency in manuring from the first to the last year of the pruning cycle. Until the cycle which is still incomplete was started, the manurial scheme has included plots that followed the original traditional practice of application at pruning time. Quite consistently the response had been lowest in the first year and has increased as time elapsed ; the four year cycle is the longest that has been put to the test. The average performance for nitrogen on a 3-year and on a 4-year cycle up-to-date is shown in Table II.

TABLE II.

Mean Nitrogen Efficiency (lb. crop response per lb. N. applied).

		1st year	2nd year	3rd year	4th year
3-year cycle (5 cycles)	...	1.1	4.1	5.0	—
4-year cycle (3 cycles)	...	0.1	1.2	3.1	4.1

When the application of manures has been delayed six months in the first year an improvement in response has been recorded

Fig. 1.

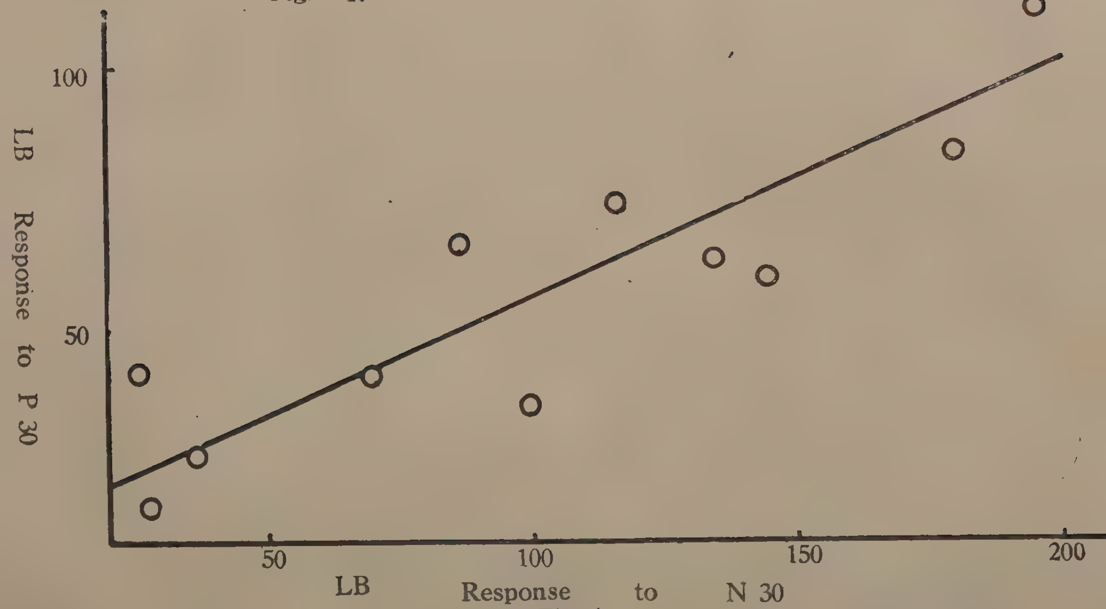


Fig. 1
Relationship between N and P response irrespective of year or cycle .

Although this effect was first noticed in regard to nitrogenous manures it is equally true as regards phosphatic manuring, and though the extension to potash manuring cannot at present be made (because potash responses have only recently emerged) it is highly probable that the same aspect will be reflected in their behaviour The effect is evidently one which is independant of the type of manure and a reasonable explanation is to attribute it to increase in size and development of the bush itself. The effect of manuring on the growth that takes place between pruning and tipping is very small. For that recovery the bush depends very largely on stored foodstuffs. When the season is unfavourable for nitrogen response it is correspondingly unfavourable for phosphate response. Figure 1 sets out results from pruning cycles in which the response to equivalent doses of nitrogen and phosphate are plotted against one another irrespective of year or position in the pruning cycle. The general trend is shown by the straight line graph. The graph establishes two points, first the significant correlation between nitrogen and phosphate response at any time. (The appropriate statistical function that expresses this, the correlation coefficient r has a value of 0.89 ; the values can vary between 0 and 1.0). Secondly that the average phosphatic response is about 44 per cent of that expected from a similar amount of nitrogen.

There is not only an increase in efficiency in manurial response within the period of the pruning cycle ; the general trend has been for efficiency to increase as the experimental period has been prolonged. When first the trial was laid down the highest efficiency index in the cycle was 4.0. In five cycles it has increased that value by fifty per cent. although there has been a constant difference between doses on the plots This observation is quite understandable If a high level of nutrition is maintained, the frame, foliage and roots of the bushes benefit and *ipso facto* become more efficient organs for the garnering of nutrient and the building up of elaborated foodstuffs that will be used in further growth. We have to deal with a perennial crop and the effect of treatments, good or bad, are bound to be cumulative.

The response to phosphatic manuring is not as simple as to nitrogen Above a certain dose, which, from evidence so far collected, seems to be in the region of 30 lb. P_2O_5 per acre, no further growth response to phosphate can be expected on typical tea soils. In a period of 12 years, the increased crop that has resulted by reason of increasing the phosphatic dose from 30 lb. to 60 lb. P_2O_5 has been only 86 pounds per acre, an average difference of only about seven pounds per annum. This difference is not one on which any reliance can be placed even in experiments as accurate as these.

Table III gives the weights of crop harvested over a period of four cycles at phosphoric acid levels of 30 and 60 lb. per acre respectively.

TABLE III.

Phosphatic Responses at High Levels.

lb. per acre per cycle of 3 years.

	2nd Cycle	3rd Cycle	4th Cycle	5th Cycle	Total
P30 ..	1892	1679	2454	2284	8309
P60 ...	1871	1701	2489	2334	8395
Diff. P60-P30	−21	+22	+35	+50	+86

Up to 30 lb. phosphoric acid per acre the response has been substantial but not as great as that from nitrogen.

The response to potash has been altogether different. For many years there was no evidence of it at all. At the end of 12 years during which some plots had been consistently deprived of potash, the total response from 40 lb. of potash was 143 pounds of which 80 lb. was provided by the twelfth-year response alone. In the succeeding cycle the gain was 225 lb. The figures are shown in Table IV.

TABLE IV.

Potash Responses.

lb per acre per cycle of 3 years.

	1st Cycle	2nd Cycle	3rd Cycle	4th Cycle	Total Cycles 1-4	5th Cycle
K0	2142	1853	1609	2322	7926	2120
K40	2148	1833	1649	2439	8069	2345
Diff.	+6	−20	+40	+117	+143	+225

Broadly speaking it has taken between 10 and 12 years for the effects of potash deficiency to show themselves in crop decline. This is not particularly surprising since the mineral feldspar, which is a prominent feature of the rocks from which our soils have been weathered, is itself rich in potash.

There is however another potash effect which has only recently come to light. It is mentioned here rather as an effect to be studied further than as something that has the degree of certainty attained in the long-standing trials described so far.

Some years ago the Indian Tea Association Experimental Station at Tocklai described an experiment on young tea which showed unmistakably that the growth of the young plant was greatly helped by heavy doses of potash (60 lb. per acre). Hitherto

on mature tea their results broadly confirmed the absence of response to potash. An experiment of a similar character was started at St. Coombs in 1944 and in 1946 before the tea was brought into bearing the growth after centreing was weighed. In the Tocklai experiment foliage leaf and wood were weighed together. In our experiment the two were separated. Under our conditions no beneficial effect of potash was discernible. During the year 1948 the bushes were pruned and brought into bearing. The experiment is laid out on patna clearings planted in the 1937-38 seasons and consists of two main units about a third of a mile apart. When the tippings were weighed it was found that both sections of the experiment gave siimilar results showing definite response to the potash manuring of the previous 3 years. The effect was not evident in the routine pluckings that have followed. Evidently the tipping was carried out at a time corresponding to some critical period. The potash did not increase the number of plucking points appreciably, otherwise the effect would be lasting. It looks as if the effect was lost at the first attempt because the period of growth was too prolonged : that view is supported by what we know of the rapidity of recovery from pruning under Assam conditions. The behaviour of the plots at bud break and the elongation of the shoots must be watched carefully after the next pruning operation. No characteristic other than growth and yield seems to be affected by potash deficiency. There are no typical leaf symptoms. In fact compared with other crops tea is remarkably free from specialized diagnostic symptoms of the common nutrient deficiencies.

TABLE V.

Response of Young Tea to Potash Manuring.
Dry weight of tippings, lb. per acre.

	Section I	Section II	Mean
K0 ...	224	140	182
K60 ...	272	171	222

During the course of these experiments on manurial response analytical data and tasting opinion on the manufactured tea have been obtained from time to time from a series of samples.

The use of nitrogenous manure makes slight differences in the composition of the extract when the teas are brewed. The results show increases in nitrogen and in caffeine (a nitrogenous compound) and a decrease in ash content which, though reliable, are technologically quite insignificant. Evans showed that on any particular estate improvement in price followed increase in the so-called tannins. The variation that 40 lb. of nitrogen makes in "Total Oxidisable Matter" (T.O.M.), which is a convenient estimate of tea polyphenols for comparative purposes, is negligible.

The results from one sevenfold series of analyses are given in Table VI.

TABLE VI.

Comparison of Tea receiving no Nitrogen and Tea receiving 40 lb. per acre of nitrogen.

(Per cent. on dry tea, except T.O.M. which is an Index Number).

		No nitrogen	With nitrogen.	Difference in favour of no nitrogen
Extract	...	41.44	41.46	−0.02
N. in extract	...	1.61	1.67	−0.06*
T. O. M.	...	233.9	232.1	+1.8
Caffeine	...	3.14	3.25	−0.11*
Ash	...	5.25	5.16	+0.09*

*Differences marked thus are reliable; the others are due to chance.

Similar analyses for teas harvested from plots receiving equivalent amounts of nitrogen in inorganic or organic form show no differences that survive statistical examination (Table VII).

TABLE VII.

Comparison between different Kinds of Manurial Nitrogen.
(Per cent. on dry tea, except T.O.M. which is an index number).

		Sulphate of ammonia.	Blood Meal.	Difference in favour of Blood meal.
Extract	...	44.24	44.26	+0.02
N. in extract	...	1.69	1.62	−0.07
T. O. M.	...	259.3	262.4	+3.1
Caffeine	...	3.28	3.25	−0.03
Ash	...	5.33	5.26	−0.07

No differences are significant.

In terms of tea tasters reports the differences in value have never on the average reached a cent on the Colombo market (in favour of no nitrogen) and on the same teas London's preference was no greater than 1/12th penny. None of these results was beyond the influence of chance. Only in the case of potash manuring have any manurial samples shown up consistently. In a series of samples over a long period London consistently preferred the teas from potash manuring and the average preference was 0.64d.

There are certain puzzling features about the data provided by our manurial experiments and these can only be clarified by

further work. It is common for the response of one nutrient to depend upon the supply and utilization of another. In the absence of sufficient phosphate for example the effect of nitrogen might be expected to be diminished. No such effect has been shown in our experiments The nutrients appear to behave independently and the total effect of nitrogen plus phosphate appears to be equivalent to the sum of the nitrogen and phosphate effects singly. There is no 'interaction' between nitrogen and phosphate. Some slight dependence between phosphate and potash effects is foreshadowed in recent results but, because minimal supplies of potash have been only of recent occurrence, it is too early to press the point. There is a good deal of luxury consumption of phosphate and potash in the tissues of tea, *i.e.*, even though no response in yield is promoted, higher doses of nutrients raise the concentration of the element in the leaves and wood. This luxury storage may be a contributory factor in masking interaction effects.

A second peculiar feature of the experimental data is that connected with the relation between total yield and response to nutrients. When fields on a commercial estate are treated consistently as regards pruning and plucking, the yield pattern of the different years of the pruning cycle shows remarkable consistence too. Broadly speaking these patterns fall into two classes, that in which the yield achieves a maximum value in the early or mid-period of a pruning cycle, after which there is a steady falling away (the 'early maximum' pattern), and that in which the annual yield increases as the pruning cycle progresses, or becomes stabilized at a recognisable 'ceiling' (the late maximum pattern). Our experiments have shown that the falling-off of annual yield in the early maximum pattern is not accompanied by a decline in the response to added nutrient, in-so-far as it can be measured by a comparison between the yield from two well defined doses. This can be illustrated by the yield comparisons in Table VIII.

TABLE VIII.

Decline in Average Crop from 2nd to 3rd year in 3-year Pruning Cycle compared with *Increase* in Response to N. in the same period.

	lb. per acre				
	Cycle 1.	Cycle 2.	Cycle 3.	Cycle 4.	Cycle 5.
Crop *decrease* (2nd year 3rd)	283	270	365	345	26
Response *increase* for 40 lb. N. (same period)	13	14	38	11	108

Yet another disturbing factor in fertilizer response is shade. We have not formally studied the effect of shade because the design of foolproof experiments presents tremendous difficulties. By the mere growing of shade, soil and micro-climatic conditions are altered in many ways. Even with artificial shade there are grave difficulties, especially on land where aspect is so changeable. Nevertheless certain observations made on experiments at St. Coombs and at Passara, which fall into line with results in India, suggest that the presence of shade blankets manurial efficiency on a short-term view.

At Passara, on an experiment with moderate grevillea shade, the nitrogen efficiency is only about half what we expect on St. Coombs on areas with sparse shade. It must be remembered however that the annual drought in Uva is another disturbing factor. At St. Coombs on a normal grevillea-shaded area nine years of manurial treatments varying by 30 lb. of nitrogen have failed to show any effect.

To conclude this short description of the work of the department carried out over two decades on the subject of fertilizer field trials, it only remains to consider its practical and advisory bearing. The practical limits of manuring with the three main nutrients have been defined with reasonable adequacy. Nitrogen can be economically used at any rate up to 80 lb. per acre, always provided that the cultural condition of the bush is good. Phosphoric acid appears to have a useful limit which is certainly not greater than an average of 30 lb. per acre. Potash in the soil is reasonably plentiful but it is wise to replace that which is regularly removed in the form of crop and pruning wood. The figure given by analysis suggests that on the average 3.5 lb. of potash are lost for every 100 lb. of crop harvested. This must be regarded as an irreducible minimum. Thus for ordinary conditions one would use nitrogen in quantities governed by a variety of agricultural and economic conditions with the knowledge that it is likely to justify its use. Phosphoric acid and potash doses would fall between the 20 and 30 lb marks. Changing ratios, or esoteric attempts to 'balance' manures appear to be singularly remote from the realities of practical tea planting. A standard mixture is as good as any other, and indeed has proved itself so during the period of fertiliser rationing.

The form in which manures can be used is varied. Though more fool-proof, the organic varieties of nitrogen are substantially dearer and scarce, and no case has ever been made out for their superiority except a doubtful one for their production of hormones. Recent work on the subject shows that there is a hormone balance

in the soil which is naturally restored from either higher or lower levels. But the use of organic artificials is not the only way to influence that balance.

The time of application of manures is important. It appears to be useless to apply manures when, for a variety of reasons, they cannot be efficiently absorbed. This suggests that some accommodation to weather conditions is advisable, but drought seems to be more unfavourable to efficient nutrient recovery than excessive rainfall. Manuring when the bush is devoid of leaf is uneconomic, and this puts out of count not only the pruning mixture, as originally conceived, but that even more extravagant curiosity the 'pre-pruning' mixture by the use of which valuable nitrogen may be absorbed into the tissues of the bush only to find its way in large part into the domestic fireplace in the form of prunings, or to be released from pruning leaf at a time when the bush can make only limited use of it. The system that has been advocated for some time, that of incremental doses increasing during the pruning cycle is empiric, but has a solid foundation of experiment and successful practice behind it.

CHAPTER 3.

THE TEA BUSH AND THE CROP.

The experimental results which have been considered in the preceding chapter have been presented in terms of crop. Indications have been given that to explain them we must look further than that part of the bush which is regularly harvested : in effect, we must look at the bush as a whole. Field experiments are empirical in both their design and results. The problem of delving deeper into the working of the bush as a whole, so as to explain and co-ordinate the field results, is one for a plant physiologist. Nevertheless, no experiment of merit, more especially with a long-term perennial crop, should stop short at measuring crop only. Between the apparent simplicity (and inadequacy) of the purely *ad hoc* approach and the intricacy of physiological research there lies a wide and varied realm of what for want of a better designation may be called crop ecology, claiming neither profundity of conception nor delicacy of technique, but nevertheless capable of throwing an occasional shaft of light on the complexities of a realistic agricultural problem. In this short chapter a few observations of this kind are considered It has been our endeavour never to be satisfied with a 'yield per acre only' point of view.

The new growth during a cycle consists of the tippings, flush, foliage and pruning wood. Of these the latter cannot be determined with much accuracy because pruning is not a standardised operation even in the sense that plucking should be. For the first four cycles of a manurial experiment data have been collected showing how the dry matter distribution of this new growth is partitioned. The foliage and wood yields are based on random samples of 1,350 bushes, the prunings of which were dried, and the leaves picked off and weighed separately.

TABLE IX.

Dry Matter Distribution

% of Total.

	1st Cycle		2nd Cycle		3rd Cycle		4th Cycle		Average	
Tippings	5)	39	4)	22	2)	17	2)	20	3)	24
Flush	34)		18)		15)		18)		21)	
Foliage		26		22		25		19		23
Wood		35		56		58		61		53
Total		100		100		100		100		100

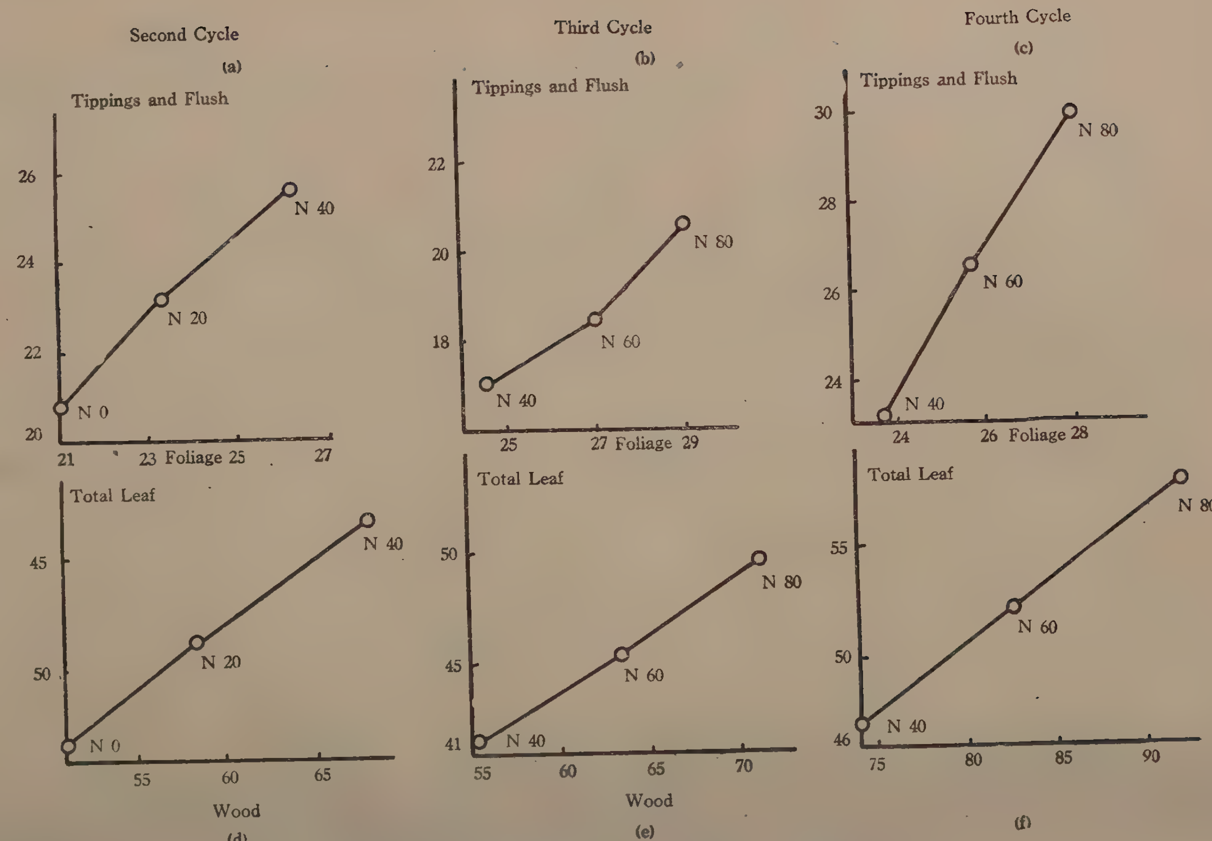


Figure 2. Relation between Yields of Leaf and Wood at varying nitrogen doses

There is considerable variation in the proportions assignable to each class, but the main source of discrepancies is the wood, for the reasons stated. A more stable classification is achieved if, recognising the rather arbitrary nature of the figure for wood, the data are recalculated in terms of total leaf.

TABLE X.

Dry Matter Distribution (without wood)
Per cent. Total Leaf.

	1st Cycle	2nd Cycle	3rd Cycle	4th Cycle	Average
Tippings	8) 60	9) 50	5) 41	5) 51	7) 51
Flush	52)	41)	36)	46)	44)
Foliage	40	50	59	49	49
Total	100	100	100	100	100

Taken together, and allowing for the crudity of the observations, it appears that of the new growth one part represents pluckable leaf, one part permanent foliage, and two parts, more or less, new wood. This is supported by results from another experiment where the proportion of flush to foliage leaf is 52 per cent. compared with 48 per cent. These observations suggest that what has been regarded as a reasonable norm in plucking allows the foliage leaf to be built up to an amount roughly equivalent to that of the plucked flush.

The flush-foliage-wood relationship can be studied in greater detail if the response to manuring is examined. In Fig. 2 a, b and c show the relationship between plucked leaf and foliage leaf at three levels of nitrogenous manuring in the second, third and fourth cycles when manurial effects were becoming distinctive. Diagrams d, e and f for the same period show the relationship between total leaf (foliage and flush) and pruned wood. The consistent behaviour of the experiment is remarkable. To all intents and purposes the response to manuring on the part of the flush is exactly paralleled by the response of the foliage. Similarly, where added nutrient has increased foliage as a whole, the effect in increasing wood has been strictly proportional. Some variability in the slopes of the straight line graphs shows that from cycle to cycle the relationship between these various categories, though consistent, is not identical, but the point brought out with greater clarity is that under a stable system of plucking and pruning, manuring affects the growth and vigour of the bush as a whole. Consequently the idea that *fertilisers* give crop at the expense of wood or foliage is a complete delusion. It is possible to produce crop at the expense of foliage and wood as has been shown by the trials on fish-leaf plucking.

TABLE XI.

Dry Matter Distribution from Two Systems of Plucking
Pruning Cycle 1940-1944, lb. per acre.

	Harvested leaf.	Residual foliage.*	Pruned wood.*	Total
(a) Fish leaf plucking	4430	1070	9350	14850
(b) Single leaf plucking	3020	2860	17400	23280
Ratio a/b	1.47	0.37	0.54	0.64

* At the end of the pruning cycle.

Here, in four years, by fish-leaf plucking the harvested leaf has been increased by nearly 50 per cent, the foliage reduced by two thirds, the wood nearly halved and, what is most important of all, *the total growth in all categories reduced by one third.* It is surprising how long the mutilation of a bush by bad plucking can be carried on whilst still showing a crop response, but when the bush as a whole is put under observation the retrogression is most marked and eventually has its effect on crop. It is possible to combine bad plucking with good manuring and for a time reap a reward in flush which suggests that manuring favours crop at the expense of wood. Such a conclusion is due to confusion of thought. Whenever the frame and foliage of a bush suffers visibly, it is more likely that the trouble lies primarily in bad management of the bush than in deficiency of manure, unless there is very clear evidence to the contrary.

The deterioration of the bush can take place to a considerable degree before the elaborated food reserves in the root are exhausted. Visual comparisons of the starch-iodine reaction in transverse sections of the roots from bushes plucked normally and those plucked to the fish leaf have shown surprisingly little difference. There is need here for detailed physiological work. The laying down of starch in the tissues will not affect a visual estimate of the density of the packing of starch grains beyond a certain critical value, above which the section appears black when stained with iodine. There may have been an appreciable withdrawal of starch from the roots of fish-leaf plucked bushes, but the evidence so far is that it has not proceeded to a degree that is common at lower elevations with a normal plucking standard. In the four-year cycle during which the bush deterioration set in, with results that have been set out previously, the index figure for starch reserves were as follows :—

TABLE XII.

Starch Reserves in Roots. Visual Indices.
Points scored (Maximum possible 192).

Months after pruning		Plucking to Fish leaf	Single leaf
26	...	176	181
32	...	165	177
37	...	*176*	*187*
42	...	186	188
48	...	*177*	*187*

The starch indices were graded from 0 to 3, and for each type of plucking there were 64 samples giving a total marks possible of 192. Only in the third and fifth sampling periods were the differences in favour of single-leaf plucking statistically reliable.

From the consideration of the distribution of growth in terms of dry matter and the analysis of the plant tissues it is possible to derive some idea of how the bush is using added nutrients as a whole and not merely for the production of crop, as was displayed in Chapter 2. The four cycles from which there are comparable data for nitrogen, phosphoric acid and potash gave the following figures for nutrient removal.

TABLE XIII.

Removal of Nutrients corresponding to 100 lb. crop.

		Nitrogen.	Phosphoric acid	Potash
(1) Flush	...	4.02	0.85	1.60
(2) Wood	...	2.36	0.70	1.87
(3) Foliage	...	2.72	0.46	1.30
Total	...	9.10	2.01	4.77
Permanently removed (1 and 2)	...	6.38	1.55	3.47

Whilst these figures must not be given undue weight, they point the way to several conclusions. They show in conjunction with those for average response to nitrogen that the efficiency of nitrogen utilization is about 20 per cent. They further show that although during the cycles concerned there was no distinguishable potash response, there was a considerable drain on potash from the soil. Even if the contributions to flush and wood only are regarded as the items permanently lost from the balance sheet of soil fertility, a 600 lb. per acre crop is removing more than 20 lb.

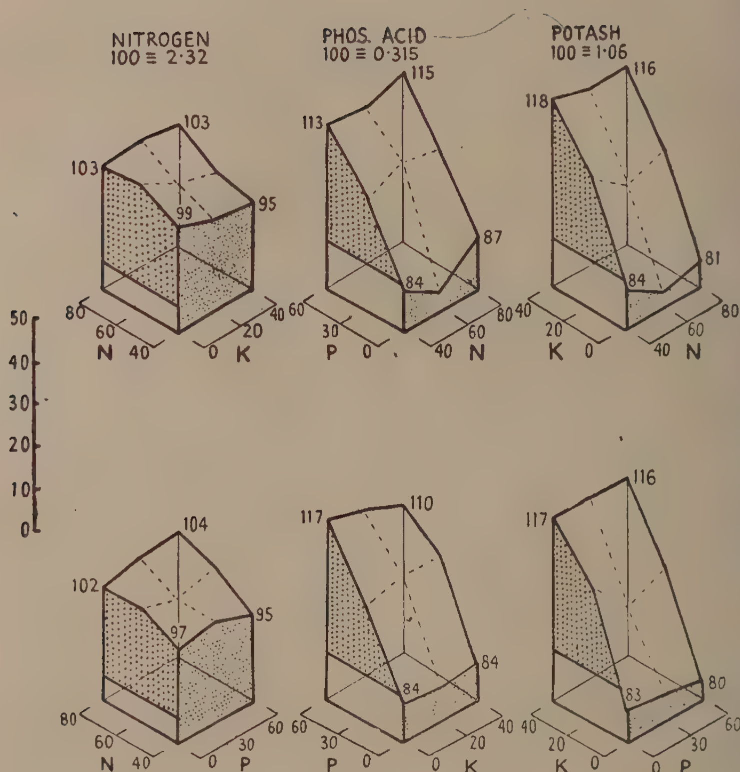


FIG. 3 Variation in foliage-leaf composition (per cent. of mean for each component respectively).

of potash per annum and it is mere prudence to see that at any rate a more than equivalent amount is contributed in the manuring scheme.

Another aspect of the analytical data used to calculate the foregoing table has to do with the effect of manuring not only on growth but on the constituents of the plant tissues. The data are somewhat complicated but their meaning is best shown diagrammatically in Figure. 3 In this diagram the results are shown as pictures of model prisms in three dimensions. The two dimensions in each instance which define the base upon which the model stands, relate to the increments of fertiliser nutrient that have been given, in lb. per acre. The third dimension, *i.e.* the height of the model, symbolizes the nutrient content of the foliage for one or other of the three nutrients N.P.K. expressed in terms of percentage of the mean. In order to save space, only the tops of the prisms are depicted. The values at each corner are printed in the diagrams. It must be accepted that the base of the prisms as shown is not the value 0, as it would be if the whole model were shown, but 75, the arbitrary level at which the models are truncated. The informative part of these diagrams is the top surface. Consider first the two prisms under the heading nitrogen. The top one shows how foliage varies in nitrogen content with the varying dressings of nitrogen and potash ; the lower with nitrogen and phosphoric acid. It will be seen that increments of fertiliser nitrogen change the composition of the leaf, but do so only to a moderate degree. At the bottom of the left-hand face is a blank unshaded portion which shows the amount of variation that must take place before reliance can be put on the interpretation that the effect is really a result of the added nutrient. The nitrogen changes are by this standard just large enough to be significant. Increments of fertiliser potash or phosphoric acid do not change the nitrogen content sufficiently to be relied on.

In a similar way the other prisms can be interpreted. In general, if a change in nutrient content of the leaf is taking place, it can be traced to the sole influence of that particular nutrient used as a fertiliser. Nitrogen affects N content, phosphoric acid changes phosphoric acid concentration in the foliage, but nitrogenous fertilizers do not change the phosphoric acid content of the leaf, nor *vice versa*. This is a different effect from the one noticeable on weeds.

The effect of both phosphoric acid and potash fertilizers is very much greater than that of nitrogen. It may be reasonably conjectured that the reason why nitrogen does not pile up in the leaf even when 80 lb. per acre is being given is because, when a certain

critical concentration occurs, it is expended in further growth. It is known that 30 lb. phosphoric acid gives a marked response in yield. It also increases the phosphoric acid content of the foliage. The increase is continued when the phosphoric application is doubled although no yield response is experienced. At this stage the plant becomes a luxury consumer of phosphoric acid, *i.e.*, absorbing, but not using the nutrient. The potash effect is an even more striking example of the same tendency. The yield response to potash developed only subsequent to the collection of this data. But the increase in potash content of the foliage is strictly proportional to the increase in manurial dose.

The observations described in this chapter are a rather heterogeneous collection which only touch the fringe of an important scientific aspect of tea culture. They may appear to be of more interest to the researcher than to the planter. Nevertheless the data are completely relevant to the practical aspects of tea growing since they illuminate a point that is often neglected. The point is that the numerous operations of cultivation and care that a tea bush demands, affect the bush as a whole even though their main intention is restricted in scope. Cultivation, manuring, pruning and plucking are hazardous undertakings if they are regarded only from the standpoint of crop. From that of the vigour and health of the bush they deserve the closest attention.

CHAPTER 4.

CULTIVATION AND WEEDS.

The essence of agriculture, and of arable agriculture in particular, is cultivation. The closed economies of undisturbed forest or grassland work at too slow a tempo for the agriculturist, and his most powerful weapon in changing a natural economy and speeding up growth is cultivation. As regards arable agriculture there never was a more contradictory slogan than that which suggests that in agricultural practice we should 'go back to nature.'

It must readily be conceded that cultivation, which was conceived in terms of benefit, often turned out detrimental in practice because wasteful processes as well as useful ones are accelerated as soon as the soil and its natural mantle of vegetation are disturbed. Successful agriculture consists of establishing a balance between benefit and waste that shall remain favourable.

Before any co-ordinated policy for cultivation can be established it is necessary to ask a number of questions of which the chief are: what kind of a crop is to be grown; what kind of a soil is it to be grown in; under what kind of weather conditions? Before passing to experimental data it will be as well to amplify these fundamental questions, keeping the tea plant in mind. Is cultivation of a permanent crop as necessary as that commonly carried out for an annual crop which has to start from seed and make all its growth each season? Is cultivation equally beneficial before a crop is planted and after it is growing? Do all soils respond to cultivation, or is it possible to damage a soil by over-cultivation? To what extent do weather conditions impose a limit on fruitful cultivation operations? What does cultivation do, not only to the soil but to the plant? Is the soil aeration encouraged by cultivation capable of producing results that outweigh root damage and soil erosion? Does cultivation help or hinder weeds?

To unravel the intricacies of soil cultivation, tilth and crop response is a task beyond the scope or powers of a single department in a small commodity research institute. The task needs tackling both in the field and in the laboratory. Some work along both these lines has been done and it has become increasingly evident that the whole complex course of events involving cultivation, weeds and soil erosion hangs together. This chapter will deal for the most part with the field side.

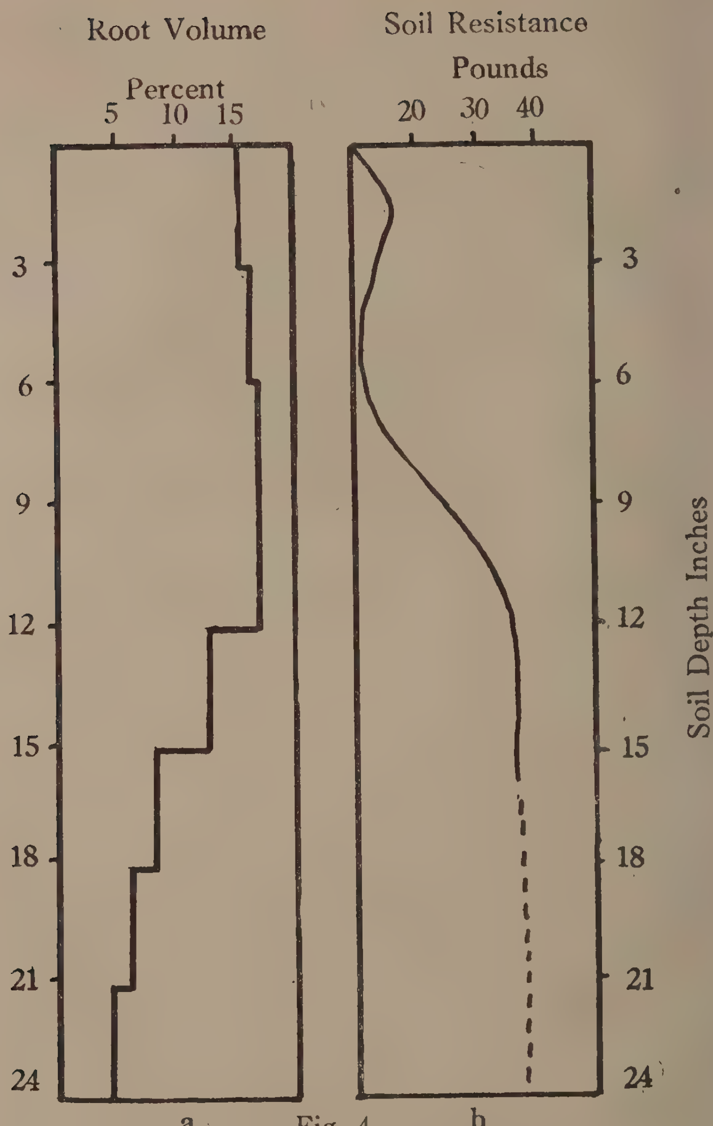


Fig. 4

Change of Root Volume (a)
and Soil Resistance (b)
with Soil Depth.

There are obviously qualitative as well as quantitative aspects of cultivation. Everything that follows is based on the assumption that the standard operation is envelope forking. What is good envelope forking and in what terms can it be defined? First as regards depth. With an 18 inch fork and adequate supervision, the average penetration is never more than 12 inches. The nature of the operation settles this and there is little difference in penetration in fields that have been regularly cultivated and those that have never received any cultivation. If a steel probe 1/3rd in. in diameter is forced into cultivated ground the resistance offered by the soil attains a maximum round about the 12 inch depth. At this depth the force needed to move the probe is about equivalent to that required to lift a 40 lb. weight. This 12 inch depth can be divided roughly into two successive six inches. In the first the soil is thoroughly broken up, and, even after nine months of normal traffic in the cultivation row, the compactness does not, on our patna soils, exceed a resistance value of 5 pounds, except in the surface two inches where a pan is formed by constant treading. Below the first six inches the resistance rises rapidly to the aforementioned 40 lb. Good envelope forking is therefore capable of breaking down clods in the first six inches and of providing easy cleavage for an additional six inches but below this produces no effect. The effect is persistant even in a normal working field. If precautions are taken to fence off the cultivated area the open structure of the soil shows no signs of destruction even after seventeen months weathering.

The relationship between soil compactness and the distribution of roots is shown in Figure 4. From this comparison it is clear that tea roots will grow with ease in the moderately disturbed first twelve inches and apparently do not need the considerable permeability present in the first six inches. But as soon as they meet a compact undisturbed subsoil their capabilities for penetration are severely curtailed. More than a hint of these technically defined limits can be seen whenever a clean soil section is made by cutting back a bank for a road or path. Instances have been noted where the position of the original planting hole penetrating the subsoil can still be clearly determined. In such instances the cavity in the subsoil is crowded with roots, though very few penetrate the subsoil itself.

Soils cultivated over a long period of years show a greater volume of feeding roots per cubic foot than those which have hardly had any cultivation at all. In the root surveys carried out by the department the volume of roots per cubic foot stood in the ratio of 1:2:3 for small holdings under minimal cultivation, relatively young tea (12 years old) and tea about 30 years old respectively. All the areas had reached maturity.

This survey confirms the account given by Mann in his monograph on Tea Soils, describing tea as a shallow-rooting species very

sensitive to the physical condition of the soil and almost incapable of penetrating unkind soils. It suggests that cultivation when carried out should be deep, though not necessarily frequent, and that in the first instance it is profitable to prepare the ground thoroughly for the reception of the young plant. Tubbs in extending this survey to young replanted tea found evidence that the effects of good cultivation persisted for as long as 8 years.

The extent of the damage that over-cultivation can do is most clearly seen by comparing the yields of plots receiving normal and specially severe cultivation. The comparison made in the experimental work of the Institute is between an annual forking and that done thrice annually. The general effect of heavy cultivation is to depress the crop slightly. Leaving out of account the first year of the experiment, when the regime of cultivation had not time to make itself fully felt, in the course of three cycles totalling 11 years the maximum effect has been 6 per cent. loss of crop and the average no more than 4 per cent. The greatest differences between the two types of cultivation were in the early stages of the experiment. The amount of damage to feeding roots that is inevitably done does not appear to handicap the bush severely. In the root surveys it is impossible to distinguish between functioning and non-functioning roots but the drop in root volume by reason of intensive cultivation was only 10 per cent. and the figure is not statistically reliable. It is evident that mere mechanical stirring of the soil is not necessary except in moderation. The detailed figures are given in Table XIV.

TABLE XIV.

Cultivation. lb. per acre per annum.

	1st year.	2nd year	3rd year	4th year.	Cycle	Cycle No.
Normal ...	179	822	646	—	549	
Intensive ...	179	774	609	—	521	
Mean ...	179	798	628	—	535	1
Diff. ...	0	-48	-37	—	-28	1936-1939
Sig. diff. ...		36	29	—	23	
Per cent. diff.	0	6.0	5.9	—	5.3	
Normal ...	251	840	1088	1154	833	
Intensive ...	242	825	1053	1102	805	
Mean ...	247	832	1070	1128	819	2
Diff. ...	—9	-15	-35	-52	-28	1939-1943
Sig. diff ..	8	32	38	55	30	
Per cent diff.	3.6	1.8	3.2	4.6	3.4	
Normal ...	245	925	1167	1188	881	
Intensive ...	251	887	1113	1160	853	
Mean ...	248	906	1140	1174	867	3
Diff. ...	6	-38	-54	-28	-28	1943-1947
Sig diff. ...	9	28	47	53		
Per cent. diff.	2.4	4 2	4.7	2.4	3.2	

To interpret these results practically it seems reasonable to say that cultivation should not be done purely for the sake of soil-stirring. Plain forking, once a regular feature in cultivation programmes, is probably an extravagance. The operations of manuring, either with artificials or with green manures and composts, involve soil-stirring and these provide all the cultivation that is necessary in the physical sense.

The problem of weeds is one of the most vexed questions with which the planter and the research worker has to deal. It is a well-known and fully authenticated fact that in India both North and South, the presence of weeds is tolerated to a degree that is unknown in Ceylon. It is permissible to hazard the opinion that this is partly due to the very prolific growth that occurs at certain seasons so that planters make a virtue of necessity and cease to speak disparagingly of weed growth. In part the contrast with Ceylon is due to the fact that for years Ceylon has pursued a policy which is an encouragement to rank weed growth. That policy can be summarised in two words, viz. scraping and hard pruning.

Scraping the soil surface as a means of eradicating weeds, leaves the soil in a very favourable state for the germination of buried weed seeds. Years of cultivation and manuring and scraping have led, in any normal field, to the accumulation of vast reserves of weed seeds awaiting a favourable chance to germinate. Surveys of weed seeds on one of the older fields under experiment gave estimates varying from 52 to 108 million weed seeds per acre in the top six inches. These figures may seem enormous, but they compare very favourably with estimates from English arable land where weeding cannot be undertaken throughout the growing season for fear of damaging the crop.

Obviously a nominal monthly weeding round is bound to favour those species that germinate and grow rapidly and can mature seed before the next periodic eradication is due. Such species are *Drymaria cordata* and *Polygonum nepalense*. The increasing dominance of these species in tea fields is attributable to the removal of virtually all other competition. On an experimental area which has been under observation for 4 years where weeding has never been more frequent than five-monthly and has on occasions been left for more than 12 months, these two species are rare finds. The land in question was patna and the dominant weeds are still those which were part of the original patna association. This area moreover shows no sign that the number of species is diminishing which is what tends to happen when one or two species dominate the surface.

The average number of species picked up by a point quadrat survey on the dates recorded have been as follows :—

TABLE XV.

No. of Species and Percentage Cover on Weed Experiment.

	No. of Species	Per cent. cover.
August, 1945 ...	10	59
September, 1946 ...	16	75
March, 1947 ...	11	69
October, 1947 ...	14	83
September, 1948 ...	19	67

The influence of pruning on weed infestation is indirectly shewn by the yield effects produced on the tea. Some time elapsed before equilibrium was set up on selectively weeded plots, (i.e.. those from which only grasses were removed) but the second and third cycles, each of four years duration, show clearly that the early stages of the cycle are the plague years for weed. There is a marked diminution in the adverse effects in the third year, and in the fourth the deleterious effect was wiped out in one cycle and was hardly distinguishable in the other. There can be no manner of doubt that, if the spread of the bush could be encouraged early in the cycle, the labour of weed eradication, which is one of the costliest items amongst the field works, would be considerably diminished.

TABLE XVI.

Effect of Selective Weeding on Crop Yield.

lb. per acre.

	1st year.	2nd year.	3rd year.	4th year.	Cycle	Cycle No.
Clean weeding ...	184	838	651	—	558	1 1936-1939
Selective ...	175	758	604	—	512	
Mean ...	180	798	628	—	535	
Diff. ...	-9	-80	-47	—	-46	
Sig. diff. ...		36	29	—	22	
Per cent. diff. ...	5	10	7.5	—	8.6	
Clean ...	256	863	1078	1103	825	2 1939-1943
Selective ...	238	801	1062	1152	813	
Mean ..	247	832	1070	1127	819	
Diff. ...	-18	-62	-16	+49	-12	
Sig. diff. ...	8	32	38	55	30	
Per cent. diff. ...	7.3	7.5	1.5	4.3	1.5	
Clean ...	268	973	1194	1181	904	3 1943-1947
Selective ...	227	833	1086	1157	830	
Mean ...	248	906	1140	1174	867	
Diff ...	-41	-154	-108	-14	-74	
Sig. diff. ...	9	28	47	53		
Per cent. diff.	16.5	14.8	9.5	1.2	8.6	

The actual losses are not as severe as might have been expected. They must always depend on uncontrollable circumstances, notably weather. Two of the three completed cycles have shown average losses of 8.6 per cent. and the other of 1.5. It would be more economical in the long run to spend more money on manures and pruning and less on weeding, in order to promote an ecological balance that would be more favourable to tea and less so to weeds.

The question of how weeds produce the yield deterioration in tea, which is undoubted on a short term view, is debatable. Weeds have always been accused of stealing manure, and so they do if they are taken off the field and burnt. This aspect will be reviewed later. But the cultivation and weeding experiments at this station give a clear indication that whilst the weeds are retained on the land, either in growth or in decay in the soil, they do not interfere with the yield response to fertilizer application.

TABLE XVII.

Yields and responses in lb. per acre per annum to Fertiliser Applications on clean and selectively weeded plots — 2nd cycle.

Manurial Application	Clean weeded	Selectively weeded
Double dose N80, P60, K40 ...	880	873
Single dose N40, P30, K20 ...	770	754
Manurial response ...	110	119

This result is not confined to an isolated year in an isolated cycle. The effect has been consistent throughout the duration of the experiment. It is indeed a remarkable phenomenon and suggests that the competition set up by weeds may perhaps be for moisture rather than for nutrient. But this must remain at present no more than a conjecture.

These experiments are not without other puzzling features. When the weed infestation has been most severe and has caused most loss, a strange relationship between cultivation treatment and weeding treatment has shown itself in the yield response of the tea. In the two years concerned the figures have superficially quite different aspects, but are in fact similar in trend. They are tabulated in Table XVIII.

TABLE XVIII.

Interaction between Cultivation and Weed Treatments.
Third Cycle 1st and 2nd years yield lb. per acre.

	1st year weeds				2nd year weeds		
Cultivation	Clean	Selective		Cultivation	Clean	Selective	
Normal	271	218	53	Normal	1009	839	170
Intensive	265	235	30	Intensive	936	837	199
Difference	6	-17		Difference	73	2	

In the first year intensive cultivation has a very slight and negligible effect on clean weeded plots but is actually superior on the selectively weeded ones. In the second year the intensive cultivation decreases yield sensibly on clean weeded plots but has only a negligible effect on the selectively weeded ones. One statement covers both these seemingly diverse results; it is that the effect of intensive cultivation, though in general harmful, is less so on selectively weeded plots than on clean weeded areas. Any attempt to explain this obscure effect must be hypothetical only, but since hypothesis is a necessary starting point for fresh inquiry, it seems worth while suggesting that the continual scraping of the soil for clean weeding may in some seasons have a recognisible effect on the surface root action of tea with consequent repercussions in yield. Whatever the explanation, the fact is that the presence of weeds diminishes whatever harmful effect extra cultivation tends to have. It must not of course be forgotten that the weeds are returned *in toto* to the soil.

Besides the stimulus given to weeds by cultivation and by scraping the soil, there is a marked effect due to manuring. It was believed in some quarters that the prevalence of weeds during the early years of the 1939-1945 war was due to a change in composition of the manure mixtures to which much larger quantities of groundnut cake were added when imports of sulphate of ammonia ceased. For nine years on one experiment no source of nitrogen other than groundnut cake had been used. A comparison between the weed infestation of these and other plots was therefore possible and to that end weeding was stopped for 3½ months in 1943. The same procedure was followed for a period of 3 months in 1944. The weeds were collected, weighed, sampled and reduced to terms of dry matter. The comparison of most relevance is between sulphate of ammonia and groundnut cake for which the yields of weeds were :—

Sulphate of ammonia ...	473 lb. per acre
Groundnut cake ...	483 „ „ „

The small difference between these figures is insignificant. In parenthesis, it is worth noting that direct germination tests gave no support to the view that groundnut cake may carry viable weed seeds.

The cessation of weeding during the period of the South West monsoon (May-August) soon encouraged a continuous carpet of weeds in plots that had been pruned only the month before the weed trial was started. It immediately became obvious that the main stimulus to weed growth was phosphoric acid in the form of superphosphate. Plots receiving no phosphate carried weeds but there was no continuous carpet. The boundary between phosphate and no phosphate plots was very sharply defined as a change from the red earth to the green carpet of weeds.

The yield increment in weeds due to phosphatic manuring was quite astonishing being no less than 250 per cent. Nitrogen had only a small but significant effect (35 per cent. increase) and potash none that was clearly distinguishable.

TABLE XIX.

Yields of weeds from various manurial treatments (lb. dry matter per acre May-August 1943).

Nitrogen (lb. N. per acre)			Phosphoric acid (lb. P2O5 per acre)			Potash (lb. K2O per acre)		
N40	N60	N80	P0	P30	P60	K0	K20	K40
387	440	525	169	587	597	483	417	452

Responses of this kind raise the question of how much nutrient is being removed from the soil by the prevalent practice of clean weeding, and this in turn has its bearing on the previously noticed fact that, provided the weed material was not removed from the site, weeds were not prejudicial to manurial response in tea. The analysis of the weed material itself showed that the removal of nutrients is considerable (Table XX). As a yard stick for the weed figures the corresponding figure for the tea crop in the previous cycle is given. These figures are derived from flush and wood, the portions of the bushes, growth which does not normally find its way back into the soil.

TABLE XX.

Comparison of Nutrient removal by Tea (1 year) and weeds (3½ months).

	lb. per acre By tea	lb. per acre By weeds	Percent. composition of weeds
Nitrogen ...	56	11	1.89
Phosphoric acid ...	12	5	0.85
Potash ...	28	21	3.46

Without suggesting that the weed figures can be multiplied thrice to make them comparable with the figures for tea, it is evident that when advantageous conditions for the growth of weeds are followed by weeding rounds getting out of hand, the drain of nutrients from the soil by weeds is of a similar order to that of the major crop.

The phosphoric acid content of weeds is smaller than that of nitrogen which again is less than that of potash. Consequently the loss of phosphoric acid due to high dosage is small. By reason of the large yield increase due to phosphate response, and the higher concentration of nitrogen and potash in the tissues, the losses of these last two expensive nutrients is severe.

Weeds are luxury consumers of potash since they increase their already high concentration of the nutrient when manured with potash but do so without increasing their yield. Phosphoric acid also undergoes luxury consumption above the 30 lb. per acre level. Increase in nitrogen has little effect on the nitrogen composition of weeds, the increased amounts imbibed being consistently and uniformly used for new growth. An effect of a different kind is that heavy phosphoric acid manuring tends to decrease the nitrogen content of the tissues. This is a characteristic that is often encountered in horticultural practice. Some of the significant changes in composition of the weed tissues are tabulated in Table XXI.

TABLE XXI.

Changes in Composition of Weeds due to Manuring.

Manurial factor and intensity.		Increase in concentration mgm. per 100 gms.	Percent. increase.
P50	...	+501 P	+82.1
K40	...	+373 K	+10.8
N	...	+95 N	+5.0
P30	...	−282 N	−15.0

Although the whole complex of weeds responds in the manner indicated in the foregoing tables, there are differences in the behaviour of individual species. Some species are actually depressed by manuring, because of the keener competition of other species. It is of interest that one of the more troublesome grasses *Digitaria longiflora* is one of these.

The chief lesson to be learned from the work so far carried out is that the weed problem is a difficult and complicated one. Nothing short of a long term study of the succession of weeds over a period of years seems likely to throw light on some of the peculiarities of weed ecology — why certain weeds after reaching a climax, such as has been described for *Drymaria,* wane in importance and are succeeded by other dominant species. One can only suspect, from the surveys already carried out at regular intervals, that time and frequency of cultivation and manuring and, above all, the prevailing weather conditions interacting with these operations must play a significant part.

It becomes plain that selective weeding costs as much as clean weeding and the selection has in any case no finality. Exploration is being carried out of a different method, viz. the extension of the time between weeding operations and the burial of the weeds in pits. Above all, these experiments show that tea, the major crop, is the best controller of weeds and consideration should be given to that fact in planning cultivation operations in general.

CHAPTER 5.

SOIL STRUCTURE & SOIL EROSION

The way in which a soil reacts to cultivation depends upon a number of factors. The texture of the soil, that is its degree of sandiness or clayiness, is important. So also is its structure which, for our purpose can be defined as its "crumbiness," the state of aggregation of the variously sized ultimate particles and the organic humus into larger particles. The moisture content at the time of cultivation introduces a very potent factor and one which exercises its effect differently according to the texture and the structure. The chemical make up of the finest particles of clay also influences the effect that cultivation has. In general, the long term effects of cultivation are deleterious to good structure and hence to high fertility. Any deterioration in structure is likely to affect the erodibility of soil in a manner that is favourable to erosion and harmful to fertility.

The soil investigations of a commodity research station obviously cannot cover much, if any, fundamental work on the properties of soils that are conducive to difficult cultivation and erosion problems. The most that can be done, having the spectre of erosion and fertility wastage constantly in mind, is, where possible, to define the soils encountered in terms of what is already known about erosion and cultivation. This chapter describes a few of the characteristics that have been used in building up a view point about Ceylon tea soils in general.

The ultimate particle sizes into which soils are graded by mechanical analysis have now been internationally fixed. They define in milimetres, or fractions thereof, the limits of diameter for various categories of particles, on the assumption that the particles are spherical which of course is not strictly the case in most instances. The categories and their limits are as follows :—

		Upper limit.	Lower limit.
		mm.	mm.
Coarse sand	...	2.0	0.2
Fine sand	...	0.2	0.02
Silt	...	0.02	0.002
Clay	...	0.002	None

These sizes are to a great extent arbitrary but not entirely so. The colloidal properties which are of such importance in determining the behaviour of a soil are very evident in the clay fraction, are considerably modified in the silt and are absent in the sands.

The essence of a good soil is that it shall contain particles of varied size, neither an excess of sand nor of clay or silt. Such soils can usually be built up into agricultural soils of good texture and structure. Extremes of climate favouring peculiarities of weathering are in general inimical to the production of an ideal soil and the soils of the wet tropics and of tea in particular are no exceptions. Tropical soils tend to be deficient in the middle-sized silt fraction and that is true of the majority of the tea soils that have been examined in these laboratories.

Table XXII gives the mechanical analysis of a typical selection of soils. The figures are percentages of the total for the three fractions, sand, silt and clay, the two grades of sand being amalgamated.

Two points emerge clearly from the consideration of these figures: they show the low value of the silt fraction mentioned earlier, and they show too that there is little difference in most examples between the composition of top-soil and sub-soil. Well marked horizons are not usually discernible in tea soils and the distinction between top and sub-soil that has been made relates to soil within and beyond the range of cultivation operations respectively. The reason for this similarity is partly that where soil volumes are great the changes in texture with depth are in any event slow, but in many instances it is obvious that the original top soil has been dissipated by erosion and that what is left is in fact a denuded sub-soil. The deficiency of silt tends to accentuate the clay-like texture, especially at high moisture contents, and this is in accordance with field observation of cultivation operations.

TABLE XXII.

Mechanical Analysis of Typical Ceylon Soils.
Percentage Composition.

Soil (Top & Sub)		Sand	Silt	Clay
(T.1	...	39	9	52
(S.2	...	34	7	59
(T.5	...	64	9	27
(S.6	...	52	8	40
(T.7	...	64	30	6
(S.8	...	64	30	6
(T.13	...	34	12	53
(S.14	...	34	18	48
(T.15	...	59	10	31
(S.16	...	61	11	28
(T.23	...	68	6	26
(S.24	...	62	10	28
(T.26	...	50	10	40
(S.27	...	48	21	31
(T.58	...	46	9	45
(S.59	...	40	9	51
(T.60	...	35	52	13
(S.61	...	35	49	16
(T.64	...	64	6	30
(S.65	...	53	7	40
Mean Top	...	52.4	11.4	36.2
Mean Sub	...	48.3	13.7	38.0

The reaction of soil to cultivation and to erosive agencies depends on structure as well as texture. When a soil is alternately wetted and dried it tends to lose its structure, that is the crumbs become broken down into smaller aggregates with the result that drainage, root penetration, moisture relationships and erodibility are all altered. A soil of 'good' structure may easily have that structure changed very rapidly by wetting : on the other hand some soils of good structure resist destruction quite markedly in this way. Water-stability of soil crumbs is therefore a very valuable property in soils. According to H. H. Bennett, the Chief of the American Soil Conservation Service, this water stability is commonly associated with soils whose 'clay' fraction, as defined above, has a silica-alumina ratio of two or less. Ceylon soils have clay constitutions of this type. The following table gives a selection of analyses from varying parts of the Island.

TABLE XXIII.

Molecular Ratios of Clay Fraction.

Locality		Ratio Silica/Alumina.
Nuwara Eliya	...	1.54
		1.92
Dimbula	...	2.09
		2.10
		2.01
Bandarawela	...	1.68
		1.89
		1.54
Badulla	...	2.05
		2.24
Matale	...	3.04
		2.27

Most temperate soils have ratios well above two. The actual degree of water stability of soils can be measured in several ways. One is to wet the soil carefully and then transfer it to a bank of sieves of various sizes and to move these sieves up and down in a vessel of water. This is continued until the lapping of the water about the soil crumbs appears to break down no more of them, as is made evident by the absence of cloudiness in the super-natant water. If the crumbs that remain in the sieves are washed off, weighed and dried, some idea of the stability can be obtained.

Table XXIV gives a typical example of the results from three independent samples of a Ceylon up-country soil (Maskeliya) in a climate of high rainfall.

TABLE XXIV.

Percentage weights of Soil retained on Sieves after wet sieving.

		10 mesh	20 mesh	40 mesh	Total
Sample 1	...	24.0	18.9	13.9	56.8
„ 2	...	21.8	19.2	15.4	56.4
„ 3	...	24.8	19.5	14.3	58.6
Mean	...	23.5	19.2	14.5	57.3
S.E.	...	.907	.178	.444	.71

In this example no less than 57 per cent. of the soil was retained in crumbs of sizes which are conventionally regarded as influencing soil properties for good.

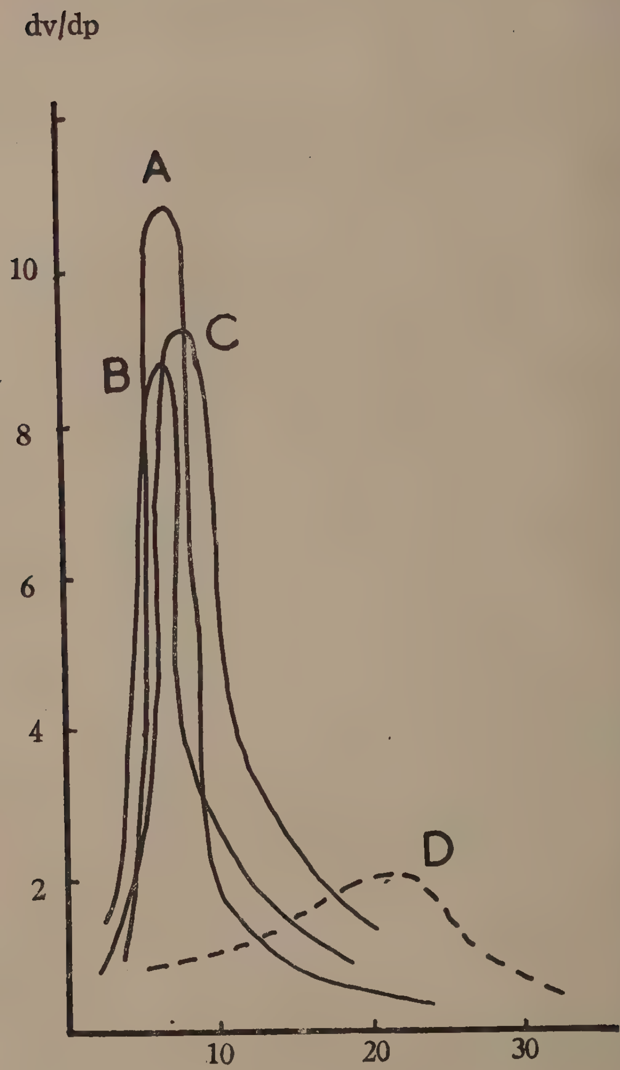


Fig. 5. Soil water withdrawal maxima after successive wettings

The disruption of soil crumbs when they are wetted and bathed in a liquid is partly due to the explosive force of the trapped air in the soil pores forcing its way out, and partly to the swelling of the colloidal particles. It is therefore of some interest to compare the behaviour of soils sieved in liquids that differ in their capacity for making colloids swell. Such a comparison can be had by using water on the one hand and a light mineral oil such as petroleum on the other (Table XXV).

TABLE XXV.

Comparison of Sieving with Water and Petroleum (Means of three).

Percentage weights of soil retained on sieves after sieving in liquid.

	10 mesh	20 mesh	40 mesh	100 mesh	Total
Water ...	7.8	22.6	30.3	29.2	89.9
Petroleum ...	9.3	23.8	31.5	28.8	93.4

Statistical examination of these results shows that none of the differences is sufficiently great to be relied on, i.e. the behaviour of soil sieved in water is substantially the same as that sieved in petroleum, and a very high state of water stability is thus demonstrated. This example is typical of wet-zone soils. The same characteristic is emphasized when a rather different technique is used, that of Childs' moisture characteristic curves. The theory on which these are based can be put in a simplified form as follows:—

When soil sieved to a standard range of particle size is saturated with water a certain amount will drain away under the influence of gravity. But some water is held in films adhering by surface tension to the particles. This water can only be withdrawn if a suction force greater than that of the surface tention is exerted. As water is removed, the films get thinner and the water becomes increasingly harder to remove. Those films whose spherical radii are the smallest are the hardest to dislodge.

By using a technique that will allow water to be withdrawn from a soil under successive increments of suction, we can plot the rate of change of moisture content by volume against the suction. In fact when such an experiment is carried out the curve produced is of the type shown in Figure 5 where A is the curve for the first wetting. It shows a peak towards the left-hand side of the graph and this indicates that most of the water was withdrawn under slight suction and that most of the water-film radii were comparatively large. If the soil is allowed to dry and is then wetted again, it is to be expected that more of the soil particles

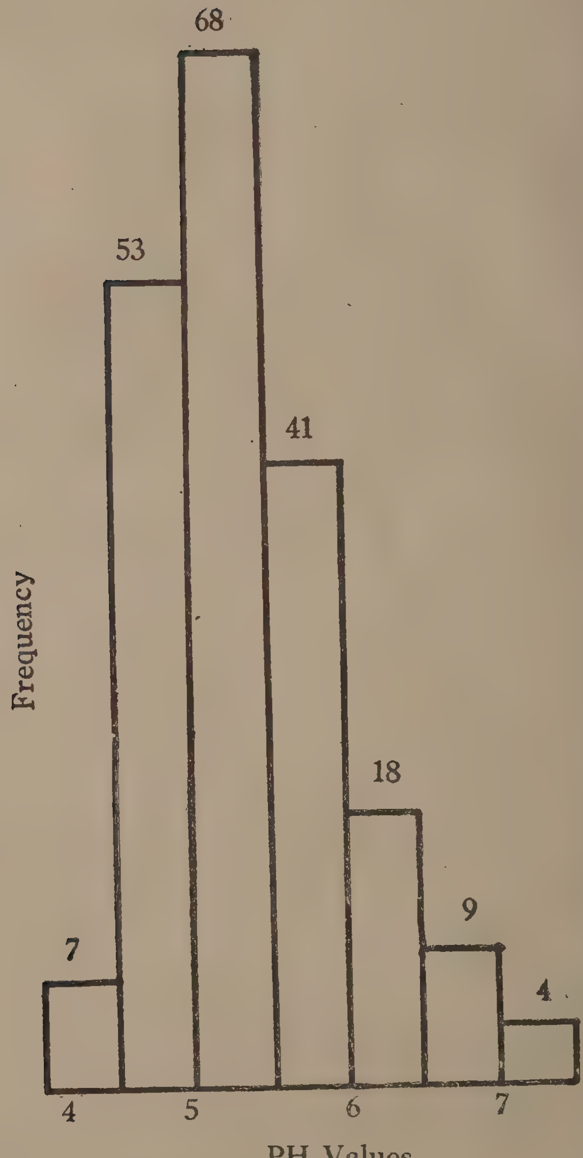
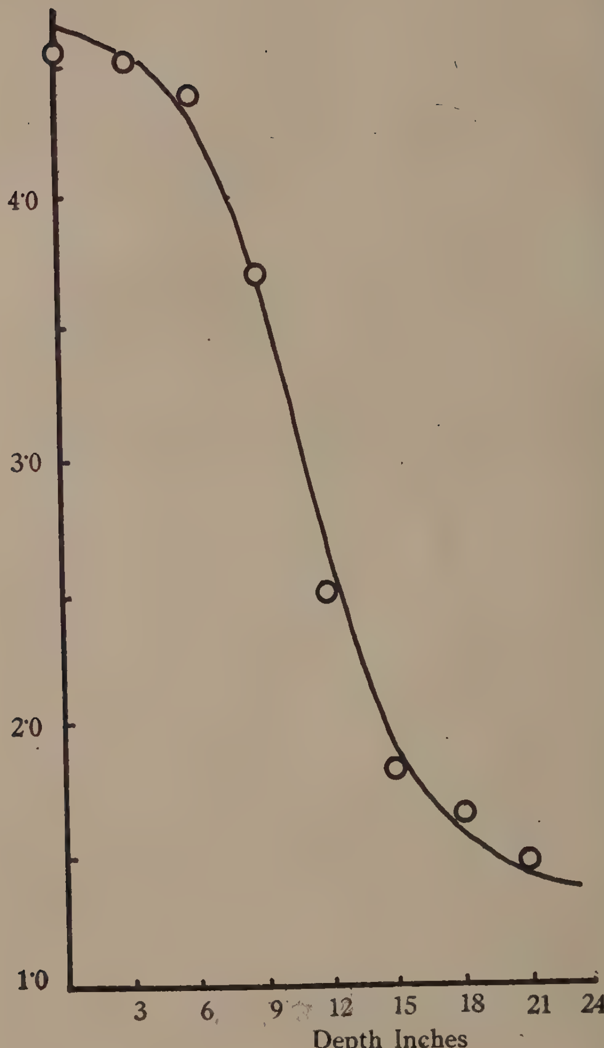


Fig. 6. Soil Reaction Distribution

will lose their crumb structure. If so, particles will on the average decrease in size so that they are packed more closely and the pores between them will diminish too. Film radii will therefore also be lessened and the suction necessary to remove water will increase. Taking these two facts together, viz. a greater number of smaller pores and a decrease in the number of large ones, i.e. randomization of particles and pore size, the curve for this wetting should show its peak further to the right as in Curve D. Since particles will break down into a variety of sizes the curve is not only shifted in position but the peak is not so noticeable. This is what actually happens in the case of an easily erodible soil that is not water-stable. But when typical tea soils are tested, even three wettings and dryings fail to dislodge the peak to any noticeable extent. In the figure, whilst curve D is a purely hypothetical one put in to illustrate the principle, curves A and B are derived from experiments with a thrice-wetted soil. Thus, using a different method of approach, we arrive at a confirmation of the fact that tea soils, and incidentally many other soils from the wet tropics, are remarkably water-stable If this were not so, not only would they be unworkable for the greater part of the year, but the losses by erosion would be even more enormous than they are already known to be.

Water stability in soils is enhanced when they are relatively free from bases. Cognate with low base status is enhanced 'acidity' or to express it more scientifically, high hydrogen-ion concentration as shown by low pH values. Fig. 6 shows a distribution diagram of 200 soils taken at random and grouped in frequencies according to the range of soil reaction. The values that lie above pH 7.0 are suspect of being associated with limestone outcrops, and since some samples were sent because tea would not grow on them, the percentage of soils above 7.0 is undoubtedly highly exaggerated. But over 80 per cent. of the soils lie between pH 4.5 and 6.0 and both the mode and the median lie in the 5.0 to 5.5 group which may be regarded as typical of Ceylon tea soils.

The importance of organic matter in the maintenance of soil structure needs no emphasis. In the montane-zone, soils with a high organic matter content were fairly well distributed when estate cultivation was started. Evidences of this are still to be seen on well managed estates opened out of patna whose contours are not too steep. The decrease in organic matter is shown in Fig. 7 where successive 3 inch samples of a patna clearing 20 years old have been analysed for carbon. Organic matter is not a definite chemical compound and consequently it is better to fix on an element that is accurately determinable and to use a conventional factor for converting to organic matter. By this method the accuracy of the



Percent Carbon Content of Soil

Fig. 7

comparison is assured. The curve which fits these points is described as logistic and displays the property that the rate of change of the carbon content is proportional to the carbon content already attained. Whilst this type of curve is typical of some kinds of biological data its relevance in the present instance is not immediately obvious. Apart from the distribution of carbon or organic matter in depth, the very high values are of note for a region with an average temperature of 70°F. and with a monthly mean range of 6°F. A further point of interest is that the carbon-nitrogen ratio of these soils is high, much higher than those of typical temperate agricultural soils. Furthermore the longer the soil has been in cultivation the lower the carbon-nitrogen ratio drops. The relationship between this characteristic and fertility is obscure, but the phenomenon has been recorded elsewhere and an explanation based on the fact that cultivation radically alters the micro-organic and and biochemical aspects of carbon-nitrogen linkage has been suggested. Actually, such a tentative explanation does not do much to illuminate the situation. It merely describes the facts in different and distinctly hypothetical terms.

TABLE XXVI.

Carbon-Nitrogen and Organic Matter content of St. Coombs Patna Soils.
Per cent.

Period of Cultivation	Carbon	Nitrogen	Organic matter (Calculated)	Ratio C/N.
Nil (virgin land) ...	5.79	0.320	9.98	18.1
10 years ...	5.71	0.320	9.84	17.8
13 years .	7.58	0.436	13.07	17.4
20 years ...	7.42	0.469	12.79	15.8
50 (estimated) ...	6.31	0.468	10.88	13.5

The general conclusion from the limited amount of detailed work that has been possible is that the tea soils of Ceylon, whilst not being of outstanding fertility, are structurally of a type that has made intensive cultivation easy. Crude and wasteful practices have ruined many soils (witness the generality of small holdings), but it is distinctly providential that our soils have been of such a nature that they could be quite severely abused without precipitating immediate disaster. It behoves agriculturists to be thankful for their good fortune and not to presume on it by careless agricultural practices.

CHAPTER 6.

COMPOSTING AND GREEN MANURING

The fertility of the soil at any given place at a particular time depends on three main factors (1) the inherent fertility of the soil when it was first converted to agricultural use ; (2) the climate to which it has been and is then subject ; (3) the system of cropping and management that has been in operation. The first two factors are outside the agriculturist's control so that efforts to conserve or improve soil fertility by human action are confined to the third. Agricultural systems are of two kinds : those based on monoculture such as tea, coffee, rubber, sugar-cane ; and those based on crop rotation made possible by the use of annual or short term crops. Rotational agriculture is superior to monoculture for many reasons. Those relating to soil conditions are two. It is possible in a rotation to choose crops making rather different or even complementary demands on the soil nutrients, and to insert courses which definitely build up rather than exploit fertility. The maintenance of soil fertility over long periods is on the whole easier in dry zone agriculture than in wet, and in temperate than in tropical climates. In neither respect is tea in a favourable position. It is perhaps surprising that tea, a monoculture in the least satisfactory of climatic regions, does not noticeably dissipate soil fertility if properly cared for. Perhaps the reason is that in terms of agricultural systems and their dependent civilizations, tropical agriculture of the plantation type is in its veriest infancy. At any rate we have no reason to be complacent ; for there are few signs after a century of effort that a relatively stable system of agriculture has been evolved for any tropical plantation crop.

The loss of fertility in tropical soils subject to high rainfall is ascribable to various causes when examined in detail, but these can all be related to the continual wastage of organic matter and soil nutrients. The most easily lost nutrient is nitrogen which can only be retained with any measure of permanence in the soil when linked to carbon in those complicated compounds which are referred to by the layman as 'organic matter.' Organic matter is of the first importance in maintaining soil fertility quite apart from the conservation of nitrogen, so that notwithstanding such extremes as fens, moors, mangrove swamps and tundras, the problem of soil fertility preservation touches that of organic matter preservation whenever it is discussed.

Under our peculiar conditions, the one constructive contribution to the solution of the problem, apart from abandoning agriculculture in favour of forestry, is green manuring.

The work of this department is not specifically concerned with the botanical and ecological aspects of green manuring though these cannot be ignored even in chemical investigations. From the viewpoint of agricultural chemistry the main concern lies in how best to make use of green manures, and in enlarging our knowledge of what happens to them in the soil.

There are two aspects to the use of shade trees, bush types, and cover crops as green manures. Firstly, those in common use are mainly leguminous. This implies that a large number of the species that are used can *directly* improve soil fertility by fixing atmospheric nitrogen *(N.B.* The well known genus *Cassia* is apparently for most part not a fixer of nitrogen). Secondly, there is the aspect previously mentioned that a growing plant garnering carbon from the air and nitrogen from the soil, and synthesising them into 'organic matter' in the plant tissues, can act as a regulator of soil nutrients by being alternately employed as a collector of nitrogen (and other nutrient elements) and as a donor. It is this aspect of green manuring that has been the main object of investigation in this department. In a word, we have been concerned with how to use green manures to the best advantage, i.e. with the problem of soil and green-manure management.

The beneficial effects of the root nodule organisms *Rhizobium* sp., which fix nitrogen, have made such an indelible impression upon agriculturists, and rightly so, that this department has to insist again and again that some (probably the greater part) of the nitrogen which is returned to the soil in a green manuring operation is derived from the ordinary soil nitrogen reserve and not from recently fixed atmospheric nitrogen. It is not therefore newly contributed nitrogen. This fact must be borne in mind whenever green manuring is under discussion. Another matter of importance, cognate to the former, is that for the purpose of estimating the manurial advantage of a green manure (in terms of so many pounds of nitrogen contributed to soil resources) it is possible to over-stress the nitrogen content of the green tissues. It is commonly assumed for example that *Tephrosia* loppings with 3.5 per cent. of nitrogen are superior to *Gliricidia* loppings with 2.75 per cent., and that this analytical difference represents an argument for growing *Tephrosia* rather than *Gliricidia.* This whole approach is the result of misconception. What matters most is the amount of nitrogen temporarily immobilized by the green manure and subsequently released.

This depends on the nitrogen composition of the tissues to some extent, but must be considered in relation to the quantity of green manure that is grown.

The tissue of a leaf has not a fixed and immutable nitrogen concentration. The younger the leaf, the higher the N. percentage. By cutting *Tephrosia* young nitrogen contents between 5 and 6 per cent. can be shown on a crop of quite negligible yield. What one gains on the swings, one loses on the roundabouts. Whenever N figures are quoted in this chapter it is to be understood that they refer to tissues at a suitable age for use as green manures, i.e. the fully developed leaf of shade trees and grass, and the loppings of bush green manures just prior to flowering. As an example of the way in which leaf composition changes with increasing age the example of tea itself may be taken. It is obvious that, supposing the flush were not required as crop, one would not use that type of leaf as green manure simply because it contained a higher per-cent. of nitrogen than the mature foliage leaf.

TABLE XXVII.

Nitrogen in various types of leaf of tea plant.

Per cent. of dry matter.

Bud and first leaf	...	4.84
Second leaf	...	4.47
Third leaf	...	4.07
Fully mature foliage leaf	...	3.48
Old foliage leaf	...	2.52

The importance of knowing the composition of green manure tissues lies in the connection between their nitrogen and carbon contents and the course of decomposition that they undergo. There is much greater variation in nitrogen content than in carbon content so that in practice it is possible to predict with some precision the type of behaviour to be expected from a knowledge of nitrogen content only.

The general conception of the carbon and nitrogen cycles has been dealt with in detail elsewhere. Here it is enough to say that, where the carbon-nitrogen ratio is high, the organisms responsible for decomposing vegetable remains are unlikely to find enough nitrogen to keep pace with their rapid multiplication, and therefore a state of available nitrogen deficiency is a foregone conclusion. Where the ratio is low, there is likely to be enough and to spare and the nitrogen released becomes available for crop nutrition, or is liable to be lost if no growing crop occupies the land. The success or failure of green manuring is therefore a question of

management. A good deal of work on the decomposition of straws and other plant remains has been done in temperate lands. It was necessary to extend that work to materials and conditions encountered in the tropics.

The range of carbon and nitrogen contents encountered amongst materials that are commonly used as green manures or as organic artificials is given in Table XXIII.

TABLE XXVIII.

Carbon-Nitrogen ratio of Waste Materials.

...	C %	N %	Ratio	Average
TYPE A.				
Dadap, *Erythrina lithosperma* ...	45.4	4.06	11	14
Gliricidia sepium ...	40.5	2.74	15	
Sunflower, *Tithonia diversifolia*	36.9	3.37	11	
Tephrosia vogelii ...	45.1	3 92	12	
Tea pruning leaf ...	43.6	2.52	17	
Weeds ...	35.0	2.01	17	
TYPE B.				
Cottonseed meal ...	38.8	7.24	5	7
Castor meal ...	47.2	5.03	9	
Groundnut cake ...	44.9	7.92	6	
Blood meal ...	41.5	11.10	4	
Waste manufactured tea ...	42.7	3.97	11	
TYPE C.				
Straw (wheat) ...	40.9	0.32	128	61
Straw (paddy) ...	34.6	0.78	44	
Manna grass *(Chrysopogon confertiflora)* ...	45.3	1.68	27	
Grevillea leaf-fall ...	48.8	1.04	47	
TYPE D.				
Farmyard manure ...	30.9	2.15	14	12
Compost ...	18.7	1.77	11	

These are typical figures, and from different samples some degree of variation must be expected, but whatever the deviation in detail, they allow the materials to be classified in four groups. First comes the green manures proper, and other allied green material such as pruning leaf and weeds. Their nitrogen content is moderate but does not fall below 2.0 per cent. and the C/N ratio lies between 10 and 20.

Type B consists of remains of a different kind, from processed materials. These are characterised by a higher nitrogen content and a lower C/N ratio lying mainly between 5 and 10.

Type C consists of vegetation that has reached various stages of maturity and its range of carbon-nitrogen ratio is very wide but always in excess of 20.

Type D is processed material of yet a different type ; material that has undergone a fermentive decomposition. Tabulation in this way makes the similarities and the dissimilarities of the materials plain. Mature materials are in a class by themselves. In the respect that is being here considered, green manures are similar to farmyard manure and compost. Organic artificial manures are plainly distinguishable from bulk manures such as farmyard manure and compost.

The trend that all the work here and elsewhere shows is that if a material has a C/N ratio less than 20, it can be relied on to decompose rapidly without any further addition of nitrogen and it will mineralize an appreciable portion of its nitrogen, i.e. such nitrogen will appear during the decomposition of the material as ammonium compounds and later as nitrate. Broadly speaking the lower the C/N ratio the more rapid the decomposition and the greater the proportion of nirogen that becomes mineralized, till eventually the materials are reduced to a complex having a ratio of 10 to 12. A single exception will be considered later.

On the other hand materials with ratios over 20 are very slow in decomposition because they have not sufficient nitrogen in their tissues to sustain the micro-organisms that do the work. The organisms will abstract from the soil any mineralised nitrogen they can find in their efforts to maintain an increasing population.

The practical interpretation of these figures is a very important one, viz. that Type C is unsuitable as a green manure or as a soil-fertility ameliorator if there is a growing crop. Types A and B are suitable for immediate use and the rapidity in conversion of nitrogen into inorganic form is greatest in Type B the 'artificial fertilizer.' We have already noticed that blood meal and groundnut cake when used as manures give yield responses that are indistinguishable from a mineral manure, sulphate of ammonia, when applied at equivalent rates. The low C/N ratio which leads to immediate and rapid ammonification provides chemical evidence that confirms the rationality of the field behaviour.

The evidence that materials of low C/N ratio are donors of nitrogen when applied to the soil and that those of high ratio are acceptors, is contained in a series of investigations from which the following typical data are taken.

TABLE XXIX.

Nitrogen transformations in Fermenting Green Materials.

MATERIAL	Original Material			Fermented material			N. factor (d)-(a)	N. loss (c)-(f)
	Organic N. % (a)	Mineral N. % (added) (b)	Total N. % (c)	Organic N. % (d)	Mineral N. (found) (e)	Total N. % (f)		
Manna grass	1·37	1·09	2·46	1·98	0·41	2·39	+0·61	0·07
Tephrosia (a)	3·46	1·11	4·57	2·72	1·56	4·28	–0·74	0·29
Vogelii (b)	3·46	nil	3·46	2·85	0·67	3·52	–0·61	–0·06
Total leaf	3·19	nil	3·19	2·53	nil	2·53	–0·66	0·66

The aim of these experiments was to determine for a whole series of materials how much available (mineral) nitrogen (if any) would have to be supplied to 100 gms. of the dry material in order to ensure its rapid and complete fermentation. If that nitrogen was in fact necessary in whole or in part, it would be absorbed by organisms and converted from mineral into organic nitrogen. The amount so converted is termed the *positive nitrogen factor* for that material. If on the other hand the supply present in the material was enough to sustain the micro-biological process of decomposition, not only would the added mineral nitrogen be unused, but it would be increased by the breaking down of the organic nitrogen of the green manures. The increase is represented as the *negative nitrogen* factor.

Table XXVIII gives the balance sheet for three materials. The first column gives the amount of nitrogen in the original. This is protein, i.e. organic nitrogen : the second column shows the added mineral nitrogen and the third the total amount present before decomposition processes set in. The next three columns trace the transformations that take place. It will be convenient to follow them in each case separately.

Comparing column (a) with column (d) for manna grass, the figures show that the organic nitrogen has increased in the fermented material by 0.61 per cent. Manna grass is accordingly a

nitrogen acceptor. The source of this nitrogen is not in doubt because the mineral nitrogen has decreased by 0.68 (Col. (b) minus Col. (e).

There has therefore been rather more lost from the mineral supply than can be accounted for by the gain in organic nitrogen but the amount is well within the limits of experimental error. Accordingly the positive nitrogen factor of this 'acceptor' material appears to be established with considerable accuracy.

A similar scrutiny of the *Tephrosia* figures (case a) shows that exactly the opposite process has taken place. On fermentation, organic nitrogen has decreased and mineral nitrogen increased to the extent of a negative nitrogen factor of 0.74. Again the gains and losses do not exactly balance, this time by a considerable amount, and it is probable that the figure 0.29 for loss represents a real loss. Such losses are apt to occur when materials rich in nitrogen are fermented even under the most favourable conditions. The inference from these results is that *Tephrosia vogelii* would have fermented quite normally if no added nitrogen had been supplied. That this deduction is correct is shown by case (b). The negative nitrogen factor in this instance is not as large as in the previous example but it is of the same order, and the net loss is negligible.

The example of tea leaf is of particular interest. As would be expected from its relatively high nitrogen content it is a nitrogen donor with a negative nitrogen factor. But the nitrogen transformation is not from organic to mineral nitrogen. The nitrogen factor and the loss are one and the same. It appears probable that when tea leaf ferments in the conditions of these experiments it releases its surplus nitrogen as elementary gaseous nitrogen.

The results in the foregoing table give a balance sheet of nitrogen gains and losses after a period of sixty days. To obtain further information on this anomalous behaviour of tea leaf the decomposition was followed more closely at fortnightly intervals. At no time in controlled experiments has any mineralized nitrogen been found when tea leaf has been composted in a laboratory scale trial. Whether a similar effect would be produced by incorporation in the soil is not yet clear.

There is a further manner in which tea leaf in its decomposition differs from that of a typical green manure or vegetable waste of the types considered heretofore. The fermented material that on a practical scale we should call 'compost' is markedly colloidal, which is one of its valuable characteristics. Good compost manufacture can be roughly gauged by seeing whether the end product

is sticky when freshly made. It is one of the peculiarities of the composting of tea prunings that the resultant material is not sticky. It is powdery and a lump falls to pieces when handled. The reason for the anomalous behaviour of tea leaf rests in the high concentration of what were once called vegetable tannins.'

During an investigation of a series of leaf materials from 'tanniferous' trees it was discovered that none of them produced the sticky mucus ordinarily associated with decomposing green manures. Moreover, any green manure could be made to behave in a similar manner if it was fermented in the presence of commercial tannin or of an extract from tea itself. The polyphenols ('tannins') appeared to inhibit the development of those micro-organisms that are responsible for synthesizing the sticky mucus. If however the polyphenols were added at a later stage, the mucus, having already been formed, retained its normal properties. It was inferred therefore that the disturbance was to the process and not merely a denaturing of the product. Table XXX gives data showing the sort of effect produced.

TABLE XXX.

Stickiness of Composts.

Materials	Loss of dry matter	pH	Stickiness test.*
Tea leaf ...	31.5	7.7	252
Green manure ...	52.6	7.85	1507
Green manure plus tea extract ...	51.3	8.62	365
Green manure plus tea extract (3 weeks later) ...	53.1	8.03	1186

* Measured in gm. units of pull required to part the plates.

The test for stickiness was a carefully standardized one based on the force necessary to pull apart smooth plates between which a standard amount of the compost had been spread as a cement and allowed to dry under a constant pressure. The data give definite information on several relevant points. First there is no doubt about the difference in behaviour of the various materials. Nor can absence of stickiness be ascribed to a failure in decomposition of the materials except in the instance of *Grevillea* where the lignified tissues are quite distinct from those of green manures proper. The decomposition of the green manures and tea extract is just as complete as that of the green manure alone. The polyphenols affect only the group of organisms contributing the stickiness and not the whole flora. Similarly the lack of stickiness cannot be attributed to unsuitable physico-chemical conditions. It is known

that such stickiness is enhanced when the reaction of the material is high and on the alkaline side. All the samples were adequately constituted in this respect. The plain conclusion is that tea and other tanniferous species such as *Gordonia* are in a class apart from the ordinary run of materials.

TABLE XXXI.

Decomposition of plant materials in relation to formation of mucus.

Material	Loss of dry matter.	pH	Stickiness test
Paddy straw ...	15.4	8.73	2,021
Napier grass ...	37.4	8.58	3,306
Sunflower ...	41.6	8.15	1,116
Tephrosia ...	28.4	8.68	1,325
Weeds ...	51.0	8.01	846
Grevillea ...	5.3	7.26	281
Gliricidia alone ...	52.6	7.85	1,507
Tea leaf alone ...	31.5	7.71	329
Gliricidia plus tea extract ...	51.3	8.62	365
Gliricidia plus tea extract later ...	53.1	8.03	1,186
Gliricidia plus Gordonia extract	51.8	7.75	324
Waste manufactured tea ...	25.4	8.09	329

Academic though these investigations may seem, they have in fact a very direct bearing on the current practices of green manuring and composting. It will have been noticed that the laboratory experiments on decomposition set out in Table XXIX showed a satisfactory conservation of nitrogen during decomposition except in the instance of green manure to which additional nitrogen was added. That was because every care was taken to prevent loss of mineralized nitrogen, i.e. ammonia. In a compost heap no such refinement can be practised and, under the generally recommended conditions of moderately high pH, ammonia and probably elementary nitrogen are lost in appreciable quantities. By way of illustration mention may be made of an advisory enquiry asking why the corrugated iron sheets of the shed, in which composting of green manures was being carried out, became rapidly corroded. Analysis revealed the presence of an incrustation of carbonate of iron and ammonia. It is an important point that such loss can take place from compost heaps protected from both rain and sun. The following data refer to a compost heap of sunflower (*Tithonia diversifolia*) sampled over a period of 140 days.

TABLE XXXII.

Loss of Dry Matter and of Nitrogen in Compost Heap

		Moisture	Dry matter loss	Nitrogen loss
		%	%	%
After 20 days	...	77.5	30.6	35.4
„ 40 „	...	72.9	53.2	53.3
„ 60 „	...	68.3	56.3	61.5
„ 140 „	...	69.8	68.0	71.5

If heaps are unprotected, then losses are likely to be made even more severe by the single processes of leaching The practical conclusion of this work is that green manures do not need composting to make their nitrogen available for crop nutrition, and that if, from a given area, green manure loppings are removed and composted there is an inevitable loss of nitrogen more or less severe in character. Compared therefore with direct green manuring, composting of readily decomposible wastes, grown on an area and returned to that area, involves a potential loss of fertility on that area. This is the core of the composting controversy as it relates to conditions in the tea industry. There has never been any question of the value of compost adequately made, and properly used. Evidence of this is reserved for a later section of this chapter. But the contribution that composting can make to tea husbandry lies essentially in a transference of fertility from outside the tea area in the form of waste material whose heterogeneity of composition makes composting essential. Composting and green manuring are not antagonistic systems but complementary ones.

A further practical deduction is that whereas nitrogen losses from the green manure compost heap are probable, similar losses from the heap made solely from tea pruning leaf are inevitable. As far as the evidence goes there seems to be no more efficient method of wasting the nitrogen present in pruning leaf than by composting. What happens to the nitrogen in question can only be inferred. As previously remarked, the conclusion seems inevitable that it is lost as nitrogen gas. The chain of processes by which this may take place needs elucidating. The war put a period on this work by making it impossible to obtain the specialised apparatus and equipment such an investigation would need. The question of how decomposition proceeds in soil as distinct from the compost heap also needs further consideration. One further point is of interest : that in-so-far as soil structure improvement is due to the colloid mucus, pruning leaf would appear to have a limited influence.

During the course of advisory work a great many analyses of compost have been undertaken. It is not the policy of the Institute to undertake routine analyses of any kind except in-so-far as they

provide data not previously obtainable. The general picture given by these analyses is that compost manufacture in Ceylon its very rough and ready. Even with homogeneous raw materials, no sort of standardization of the manufactured product seems attainable. Too often, in fact, composting degenerates into something no better than the rotting down of a way-side rubbish heap. The main defect of Ceylon composts lies in the fact that very few of the samples sent for analysis really justify the designation compost. Very rarely does more than 50 per cent. of the sample consist of organic matter and frequently only 20 to 25 per cent. is compost ; the rest is merely soil. Of the organic matter present an average of about 70 per cent. is decomposed into humic substances that are soluble in alkali. The cost of moving, turning and distributing tons of material of which the greater part is inert mineral matter makes the value of such material very problematical.

Where compost is carefully made and used the effects are unmistakable. From the years 1932-35 inclusive, experimental areas on St. Coombs were given an annual application of compost made by the Adco process at the rate of 15 tons per annum. This compost was made of cut manna grass, sunflower and green manures grown in ravines. The product was of high quality and since all the materials came from extraneous sources, the applications represented a fertility increment of 540 lb. of nitrogen, all told. To put this figure in perspective it may be mentioned that the total soil nitrogen in the first foot of the area to which it was applied amounted to about 10,000 lb. per acre.

The effects of this compost on the tea which was brought into bearing the year following the last application are shown in Table XXXIII.

TABLE XXXIII.

Adco Effects.

lb. per acre.

	Adco	No Adco	Response	
1st year ...	196	163	33	1st cycle 1936-1939
2nd year ...	878	718	160	
3rd year ...	706	548	158	
Mean ...	593	476	117	
1st year ...	261	232	29	2nd cycle 1939-1943
2nd year ...	874	791	83	
3rd year ...	1144	995	149	
4th year ...	1256	999	257	
Mean ...	884	754	130	
1st year ...	251	244	7	3rd cycle 1943-1947
2nd year ...	927	884	43	
3rd year ...	1175	1104	71	
4th year	1210	1137	73	
Mean ...	891	842	49	

The first cycle shows substantial increases in crop following the now familiar pattern that responses are greater in the later years of the cycle. The second cycle improves on the first but at the end of the third, i.e. after 11 years, a marked decline has set in. Nevertheless the average crop increment is still in the neighbourhood of 50 lb. per acre. Over the whole period the average is 96 lb. per acre.

The apparent efficiency of the nitrogen added as compost is remarkably high. The calculated over-all efficiency index for this experiment does not exceed 2.2 lb. of crop per lb. of N. used. The total crop increment from compost is 1063 lb. which on this reckoning needs 494 lb. of N. As a percentage of the 540 known to have been added this reaches the high value of 90 per cent. This is of course only a theoretical calculation. There are other factors involved. All the experimental work of the Institute supports the view that, as may be expected, in a perennial crop, there are cumulative effects. If the size and vigour of the bush is improved it becomes a more efficient organism in relation to nutritional supplies from no matter what source. There is no cause to invoke esoteric explanations for the benefit that obviously has proceeded from this manurial operation : residual value of bulk manure and cumulative effect are rational explanations.

The behaviour of artificial fertilizers in conjunction with compost is of more than ordinary interest, since opinion tends to be divided rather crudely into two opposing schools advocating either compost or fertilizers.

From Table XXXIV it is clear that the effect of fertilizer applications is as marked on the areas treated with compost as on those where artificial manures only are used. Indeed, taking them at their face value, the effectiveness of the artificials is slightly enhanced by the dosage of Adco compost. The differences are of an order which is only probably significant but such an effect is in line with similar ones experienced on temperate crops in annual husbandry. This is the nearest approach to a valid interaction effect (as defined in Chapter 2) that manurial trials here have produced.

TABLE XXXIV.

Effects of Composts on Response to Added Fertilizer.
lb. per acre.

	Single dose N40	Double dose N80	Response
First Cycle			
Compost present ...	572	615	43
Compost absent ...	462	491	29
Response ...	110	124	14
	Single dose N40	Double dose N80	Response
Second Cycle.			
Compost present ...	822	946	124
Compost absent ...	701	807	106
Response ...	121	139	18
	Single dose N40	Double dose N80	Response
Third Cycle			
Compost present ...	822	960	138
Compost absent ...	796	888	92
Response ...	26	72	46

There is one other notable effect that the compost has made clear; which is that in establishing green manures, compost is of considerable assistance. The experiment under review was laid out on an area in which dadap made very poor progress owing, amongst other reasons, to infestation with the root knot eelworm (*Heterodera marioni*). The originally planted stumps and their supplies had a high mortality on the untreated plots, but they survived and reached maturity on the compost plots. This is in accordance with findings elsewhere on the influence of bulk manure or green manure on eelworm infestation. In part it is a nutritional effect, enabling the plant to maintain growth, particularly root growth, in the face of the limitations imposed by the production of galls. In part it is probably also due to the encouragement of other nematodes that are predaceous on the parasitic eelworms.

Like most operations, composting and green manuring can be overdone particularly in nursery work and in supplying programmes. A simple arithmetic calculation will show that intensive reconditioning of nurseries or composting of holes for planting applies an

effective quantity per acre that is on the scale of hundreds of tons rather than a mere ten or fifteen. These high doses can and do produce secondary effects in the soil which are disadvantageous. The bad effects most usually encountered are waterlogging and an adverse localized zone of soil reaction, due to the alkalinity of the compost, which effectively prevent normal root growth and expansion. The net result is the same, i.e. bitter-off disease.

A question that frequently arises is whether the burial of pruning leaf is more beneficial when fresh than when dry. There appears to be some fear that the process of drying will cause the loss of some essential nutrient. This is not so ; but if pruning leaf is allowed to rot on the surface of the ground, some loss is bound to occur. The conditions under which loss has been established are when periods of rain and sun alternate. But provided the pruning leaf is forked in as soon as it can be easily detached from the branches, there is no loss. Pruning leaf left to rot on the surface will behave in a manner similiar to that shown by sunflower in Table XXVI.

APPENDIX I. A.

DRY MATTER YIELDS FOR NITROGEN TREATMENTS (Lb. per acre)

	Tippings	1st year	2nd year	3rd year	Total Flush	Total 1	Foliage	Total 2	Wood	Total D.M.	Cycle years
N0	296	502	878	582	1962	2258	1547	3805	2052	5857	
N20	316	516	942	672	2130	2446	1560	4006	2177	6183	
N40	326	527	1025	742	2294	2620	1761	4381	2514	6895	1930—33
M	313	515	948	665	2129	2441	1623	4064	2248	6312	Cycle 1.
* Sig. D.	20	23	49	48	113		183		350		
N0	432	393	766	482	1641	2073	2100	4173	5200	9373	
N20	482	411	847	571	1829	2311	2330	4641	5920	10561	
N40	508	429	943	673	2045	2553	2620	5173	6880	12053	1934—37
M	474	411	852	575	1838	2312	2350	4662	6000	10662	Cycle 2.
Sig. D.	47	24	50	38	109		195		525		
N40	215	414	626	443	1483	1698	2457	4155	5557	9712	
N60	228	435	673	505	1613	1841	2697	4538	6357	10895	
N80	260	462	741	596	1799	2059	2903	4962	7123	12085	1937—40
M	234	437	680	515	1632	1866	2686	4552	6346	10897	Cycle 3.
Sig. D.	16	30	37	37	98		219		570		
N40	237	509	962	611	2082	2319	2373	4692	7399	12091	
N60	283	555	1081	737	2373	2656	2557	5213	8268	13481	
N80	317	599	1209	869	2677	2994	2777	5771	9206	14977	1940—43
M	279	554	1084	739	2377	2656	2569	5225	8291	13516	Cycle 4.
Sig. D.	29	37	61	50	134		242		749		
N40	331	426	853	778	2057	2358	No samples taken.				
N60	366	438	913	877	2228	2594					
N80	427	459	984	1017	2460	2887					1943—46
M	375	441	917	891	2248	2623					Cycle 5.
Sig. D.	46										

* P = ·05

APPENDIX I. B.

DRY MATTER YIELDS FOR PHOSPHATE TREATMENTS (Lb. per acre).

	Tippings	1st year	2nd year	3rd year	Total Flush	Total 1	Foliage	Total 2	Wood	Total D.M.	Cycle Years.
P0	458	398	817	537	1752	2210	2274	4484	6003	10487	
P30	493	415	880	597	1892	2385	2370	4755	5882	10637	1934—37
P60	471	421	859	591	1871	2342	2413	4755	6108	10863	
M	474	411	852	575	1838	2312	2352	4665	5997	10662	Second Cycle
Sig. D.	47	24	50	38	109		195		525		
P0	213	419	634	466	1519	1732	2530	4262	5810	10072	
P30	248	445	700	534	1679	1927	2690	4617	6513	11130	1937—40
P60	243	448	707	546	1701	1944	2837	4781	6713	11494	
M	235	437	680	515	1633	1868	2686	4553	6345	10899	Third Cycle
Sig. D.	16	30	37	37	98		219		570		
P0	243	526	1004	659	2184	2432	2449	4881	7590	12471	
P30	297	567	1118	769	2454	2751	2543	5294	8395	13689	1940—43
P60	297	569	1131	789	2489	2786	2714	5500	8888	14388	
M	279	554	1084	739	2376	2656	2659	5225	8291	13516	Fourth Cycle
Sig. D.	29	37	61	50	134		242		749		
P0	323	412	888	828	2128	2451					
P30	399	454	924	906	2284	2683					1943—46
P60	403	457	939	938	2334	2737	No samples taken.				
M	375	441	917	891	2249	2624					Fifth Cycle
Sig. D.	46										

APPENDIX I. C.

DRY MATTER YIELDS FOR POTASH TREATMENTS (Lb. per acre)

	Tippings	1st year	2nd year	3rd year	Total Flush	Total 1	Foliage	Total 2	Wood	Total D.M.	Cycle years
K0	312	518	952	672	2142	2454	1549	4003	2161	6164	
K20	309	509	932	653	2094	2403	1668	4071	2284	6355	1930—33
K40	317	517	961	670	2148	2465	1651	4116	2298	6414	
M	313	515	948	665	2128	2441	1623	4063	2248	6311	Cycle 1.
Sig. D.	20	23	49	48	113		183		350		
K0	457	419	860	574	1853	2310	2303	4613	5900	10513	
K20	465	409	851	569	1829	2294	2413	4707	6102	10809	1934—37
K40	499	407	845	581	1833	2332	2340	4672	5990	10662	
M	474	412	852	575	1838	2312	2352	4664	5997	10661	Cycle 2.
Sig. D.	47	24	50	38	109		195		525		
K0	228	435	671	503	1609	1837	2670	4507	6297	10804	
K20	235	443	685	511	1639	1874	2683	4557	6307	10864	1937—40
K40	241	434	684	531	1649	1890	2703	4593	6433	11026	
M	235	437	680	515	1632	1867	2685	4552	6346	10898	Cycle 3.
Sig. D.	16	30	37	37	98		219		570		
K0	266	559	1062	701	2322	2588	2464	5052	7666	12718	
K20	277	550	1085	736	2371	2648	2673	5321	8908	14229	1940—43
K40	294	553	1105	781	2439	2733	2569	5302	8298	13600	
M	279	554	1084	739	2377	2656	2565	5225	8291	13516	Cycle 4.
Sig. D.	29	37	61	50	134		242		749		
K0	332	420	878	822	2120	2452					
K20	380	450	932	899	2281	2661					1943—46
K40	413	453	941	951	2345	2758	No samples taken.				
M	375	441	917	891	2249	2624					Cycle 5.
Sig. D.	46										

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